Influence of the Clearance of the Transmission Mechanism of the Transmission Characteristics

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Abstract. The transmission mechanism is composed of a bearing cover, a rocker arm cover, a rocker arm, a shaft sleeve, a sleeve, a bushing, and a bearing. For a small space and weak rigidity servo drive mechanism, its clearance has a greater impact on static servo characteristics such as swing angle response and loop width. In this paper, the clearance of the transmission mechanism and the play clearance of the bearing are analysed, and the influence on the servo characteristics is obtained.

1. Introduction
The transmission mechanism is composed of a bearing cover, a rocker arm cover, a rocker arm, a shaft sleeve, a sleeve, a bushing, and a bearing. For a small space and weak rigidity servo drive mechanism, its clearance has a greater impact on static servo characteristics such as swing angle response and loop width. In this paper, the clearance of the transmission mechanism and the running clearance of bearing are analysed, and the theoretical calculation is verified by simulation to obtain the influence of the transmission system clearance on the servo characteristics of the transmission mechanism with small space and weak stiffness.

2. Introduction to Design of Transmission Mechanism
The rudder surface transmission mechanism’s schematic diagram is shown in Figure 1. The length of the two connecting axes of the rocker arm is 77.4mm[1]. When the rudder deflection angle is 0°, the angle between the rocker arm and OYVL in the XVLOYVL plane is 10.3°.

2.1. Key and keyway size tolerance
Rudder shaft flat key width tolerance is 8.0-0.01mm, key height tolerance is 7.0-0.01mm. The key groove width tolerance on the rudder shaft is 8.0+0.01mm, and the upper hub width tolerance of the flat tail rocker arm is 8.0-0.015mm. The hub and key are matched with a clearance of less than 0.01mm.

Figure 1. Schematic diagram of transmission mechanism
2.2. Dimension tolerance of electromechanical actuator interface
The electromechanical actuator and the rocker arm are connected to the lugs, the electromechanical actuator and the actuator support are connected to the lugs are all single-ear piece lugs, which are connected by a pin assembly, the pin assembly includes a pin, a nut, and an opening Pin with lug width $100_{-0.1}$ mm. Uniform specification of connecting pin, pin diameter $\phi 12_{-0.016}$ mm. The diameter of the hole connecting the steering gear to the rocker arm is $\phi 12^0_{-0.008}$ mm, and the diameter of the hole connecting the steering gear to the steering gear base is $\phi 12^0_{-0.005}$ mm.

The tolerance diameter of the double ear holes of the pin of the steering gear and the double ear holes of the rocker arm is $12^0_{+0.2}$ mm. The width of the double ears of the rocker arm and the electromechanical actuator base is $18_{-0.0}$ mm. The centre of the double ear holes is more than 18mm from the inside. The specific size chart is shown in Figure 2.

3. Clearance analysis
Drive steering system clearance composition is shown in Figure 3, it includes [2]:

a) Assembly clearance between rudder shaft, key and rocker arm;

b) Assembly clearance between rocker arm, pin shaft and steering gear;

c) Assembly clearance between steering gear, pin and steering gear base.

3.1. Assembly clearance between rudder shaft, key and rocker arm
The maximum clearance between key and keyway on the rudder shaft is 0.02mm, the theoretical maximum clearance between key and upper hub of the rocker arm is 0.025mm, the theoretical overall maximum clearance is 0.045mm. During actual assembly process, the key and the hub are matched, and the matching requirement is less than 0.01mm, the maximum gap between shaft key and hub is 0.01mm, the actual overall maximum gap is 0.03mm.

3.2. Assembly clearance between rocker, pin shaft and steering gear
The maximum clearance between the pin shaft and the rocker arm is 0.016 mm, and the maximum radial clearance between the pin shaft and the end bearing of the rudder joint bearing is 0.016 mm.

3.3. Assembly clearance between steering gear, pin and steering gear base
The maximum clearance between the pin and the rudder base is 0.016mm, and the maximum radial clearance between the pin and the single lug end of the rudder is 0.016mm.

3.4. Clearance calculation of servo drive system

3.4.1. The angular deviation caused by the gap of the servo drive system. According to the triangular relationship of the transmission system, the angle caused by the clearance between the pin and the steering gear base and steering gear is: $\theta_1 = \arcsin \theta_1 = \arcsin \left( \frac{0.016 + 0.016 + 0.016 + 0.016}{77.4} \right) = 0.0474^\circ$. The angle caused by the clearance between the key and the rudder shaft and rocker arm is: $\theta_2 = \frac{0.03}{14} = 0.123^\circ$. The angular deviation due to the gap is $\theta_2 = 0.0474 + 0.123 = 0.1704^\circ$. According to the clearance analysis of the servo drive system, the limit angular deviation due to the clearance is 0.1704 °.
3.4.2 Angle deviation caused by load: The rudder shaft system is shown in Figure 4, where A and B represent the intersection of the cross section and the axis of the rudder shaft support bearing, A is the inner bearing, B is the outer bearing, C is the intersection of the cross section of the rocker arm and the axis, and D is Control the origin of the local coordinate system of the rudder surface[3].

![Figure 4](image)

**Figure 4.** Rudder axis system and rudder axis coordinate system

When a torque is applied through a steel plate and an angular displacement sensor is used to measure the rotation angle, the state of the rudder shaft and bearing is shown in Figure 5.

**Table 1.** Six-component load.

| Items | Fx (N) | Fy (N) | Fz (N) | Mx (Nm) | My (Nm) | Mz (Nm) |
|-------|--------|--------|--------|---------|---------|---------|
| 1     | 0      | 0      | 0      | 0       | 0       | 380     |

As shown in Figure 5, point D is the origin of the local coordinate system of a certain control rudder surface. When the load shown in Table 1 is taken, the forces on the internal bearing point A, the external bearing point B, and the point C of the rocker arm are shown in Table 2.

**Table 2.** Force of rudder shafting

| Items | Point A | Point B | Point C |
|-------|---------|---------|---------|
|       | Fy (N)  | Fz (N)  | Fy (N)  | Fz (N)  | Fy (N)  | Fz (N)  |
| 1     | 3133    | 645     | 1876    | 451     | -5036   | -951    |

Due to the existence of the gap, the structure is deformed under the load of point D under the load of points A, B, and C. Due to the large stiffness of the rudder shaft, the relative deformation of A, B, C, and D is finally formed as shown in Figure 6.

![Figure 5](image)

**Figure 5** Unloaded rudder shaft and bearing

![Figure 6](image)

**Figure 6** Deformation rudder shaft and bearing

When the AB distance is 70mm, if the A point does not move, the B point is deformed by 1mm along the Y or Z direction due to the gap, and the rudder axis deflection angle is 0.82°. Therefore, the gap of the transmission mechanism becomes larger due to loading[4], which will cause the swing angle of the rudder shaft relative to the theoretical position, resulting in excessive deviations in indicators such as the loop width.

3.5 summary

According to the clearance analysis of the servo drive system, the limit angular deviation due to the clearance is 0.1704°. Due to the large gap of the transmission mechanism due to loading, the rudder axis deflection angle was 0.82°. The total deflection angle caused by the clearance of the transmission mechanism is 0.9904°.
4. Analysis of influence of bearing play clearance on measurement angle

4.1. Theoretical analysis

In the case of shaft deflection, the direction of the axial travel gap is uncertain, and the internal and external bearings of the radial clearance are reversed[5]. Based on the local coordinate system identified in Figure 4, the clearance and tolerances affect the shaft deflection. The calculation results of the first 4 items in Table 3 are theoretical conditions. The main factors include the axial and radial clearance of the inner and outer bearings. The axial clearance of the outer bearing is 0.25 mm, the axial clearance of the inner bearing is 0.2 mm, and the radial bearing of the outer bearing The gap is 0.06mm, and the inner bearing is 0.05mm. The theoretical maximum gap between the inner bearing and the mount is 0.036mm. The axial clearance can move positively or negatively along the X axis of the local coordinate system, so there are four cases after permutation and combination.

If the outer bearing has excessive axial running clearance, take 2mm as an example, according to the normal maximum radial running clearance of 0.06mm, double the normal maximum radial running clearance of 0.12mm, and the normal maximum radial running clearance. Calculate 3 times 0.18mm and 4 times 0.24mm of normal maximum radial play clearance. At the same time, the maximum theoretical clearance between the inner bearing and the mounting seat is 0.036mm, and the calculation is shown in Table 3.

Table 3. Rudder shaft deflection calculation

| Items | External Bearing | Internal Bearing | Off-axis angle | Radial clearance of outer bearing |
|-------|------------------|------------------|----------------|----------------------------------|
|       | X                | Y                | X              | Y                               |                                  |
| 1     | -2               | 0.06             | 70.3           | -0.086                          | 0.12°                            | 0.06mm                          |
| 2     | -2               | 0.06             | 70.7           | -0.086                          | 0.12°                            | 0.06mm                          |
| 3     | 2                | 0.06             | 70.3           | -0.086                          | 0.12°                            | 0.06mm                          |
| 4     | 2                | 0.06             | 70.7           | -0.086                          | 0.12°                            | 0.06mm                          |
| 5     | -2               | 0.12             | 70.3           | -0.086                          | 0.16°                            | 0.12mm                          |
| 6     | -2               | 0.12             | 70.7           | -0.086                          | 0.16°                            | 0.12mm                          |
| 7     | 2                | 0.12             | 70.3           | -0.086                          | 0.17°                            | 0.12mm                          |
| 8     | 2                | 0.12             | 70.7           | -0.086                          | 0.17°                            | 0.12mm                          |
| 9     | -2               | 0.18             | 70.3           | -0.086                          | 0.21°                            | 0.18mm                          |
| 10    | -2               | 0.18             | 70.7           | -0.086                          | 0.21°                            | 0.18mm                          |
| 11    | 2                | 0.18             | 70.3           | -0.086                          | 0.22°                            | 0.18mm                          |
| 12    | 2                | 0.18             | 70.7           | -0.086                          | 0.22°                            | 0.18mm                          |
| 13    | -2               | 0.24             | 70.3           | -0.086                          | 0.26°                            | 0.24mm                          |
| 14    | -2               | 0.24             | 70.7           | -0.086                          | 0.26°                            | 0.24mm                          |
| 15    | 2                | 0.24             | 70.3           | -0.086                          | 0.27°                            | 0.24mm                          |
| 16    | 2                | 0.24             | 70.7           | -0.086                          | 0.27°                            | 0.24mm                          |
As shown in Table 3, when considering the play clearance, the deflection angle of the rudder shaft should be about 0.12°-0.27°, which will cause the rudder shaft to sway from the theoretical position, resulting in excessive deviations in indicators such as the loop width.

4.2. Simulation analysis
The effect of bearing play clearance on the measurement angle was calculated by simulation analysis[4]. The overall finite element model is used as the analysis object, and the influence of the body structure on the stiffness and force transmission characteristics of the inner and outer bearing supports is fully considered. The local structure of the bearing support is also simulated by shell elements.

There are three cases to discuss the effect of bearing play clearance. In each case, bearing deformation is not considered[3]. By default, the rigidity of the bearing itself is much greater than the overall rigidity of the support and the body structure.

4.2.1. Without considering the influence of the rudder shaft. Without considering the influence of the rudder shaft, the maximum deformation occurs at the inner bearing support, and the maximum deformation is 0.189mm, as shown in Figure 7.

4.2.2. With the effect of rigid rudder axis. Temper the rudder shaft and calculate the deformation. The analysis result is shown in Figure 8. The maximum deformation of the structure appears at the outer edge web of the inner bearing, and the maximum deformation is 0.048mm.

4.2.3. With the influence of elastic rudder axis. Considering the influence of the rudder shaft stiffness, the analysis is performed. The rudder shaft cross section is simulated with a variable cross section. The outer diameter of the inner bearing is 40 mm, the inner diameter is 26 mm, and the length is 35 mm. 52mm, at the connection with the outer bearing, the outer diameter is 50mm, the inner diameter is 26mm, and the length is 47.5mm. The calculation result is shown in Figure 9. The structure’s maximum deformation value 0.05mm occurs at the outer edge of the inner bearing.
4.3. Summary
Combining the deformation of the inner and outer shaft positions under the three analysis conditions, it is concluded that the corresponding rudder shaft deflection angle should be about $0.15^\circ$ - $0.32^\circ$, which is basically consistent with the numerical analysis. This deflection angle caused by the running clearance of the bearing will cause a sway angle of the rudder shaft relative to the theoretical position, which will lead to excessive deviations in indicators such as the width of the loop.

5. Conclusion
In this paper, a clearance analysis is performed according to the design requirements, bearing characteristics, selection, and design of the transmission mechanism. The transmission clearance of the entire system is calculated. The measurement limit angular deviation caused by the clearance is analyzed. Come to the following conclusions:

1) For a transmission mechanism with stiffness in a small space, the clearance of the transmission system is small, which translates into a change of angle of $0.9904^\circ$

2) For a transmission mechanism with a rigidity in a small space, the play clearance on one side of the bearing has less deformation on the rudder shaft, which translates into a change in the angle of $0.15^\circ$ - $0.32^\circ$ and an overall change of $0.3^\circ$ - $0.64^\circ$

Based on the above two angle changes, the angle change caused by the clearance of the transmission system and the running clearance of the selected bearing is $1.2904^\circ$ - $1.6304^\circ$, which causes the rudder shaft to produce visible vibrations, and has impact on static servo characteristics such as swing angle and loop width.

References
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