Design for Brake Device of Rudder Pedal Based on Torsion Bar

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Abstract. As airborne equipment, the rudder pedal is used by pilots to control the rudder deflection by foot, and it has two functions of apply rudder and brake. As many disadvantages existing in traditional brake device, such as complex structure, large volume, heavy weight, a brake device of integrated rudder pedal based on torsion bar is designed. The device, using a torsion bar and an angular command sensor, realizes the brake device function of integrated rudder pedal. The design methods of spare functional parts of brake device are introduced in detail. The check calculation of torsion bar, design index of brake command sensor, kinematics simulation analysis of brake device and weight comparison after lightweight design are given. The practical application shows that the principle of the brake device is correct and it has the advantages of compact structure, high utilization, lightweight and high linearity.

Keywords: Integrated pedal · Torsion bar · Brake device · Lightweight design

1 Introduction

The rudder pedal belongs to the aircraft flight control and operation system. It is an air borne equipment for pilots to send heading deflection control and brake command signals. The integrated rudder pedal generally integrates two functions: rudder and brake [1, 2]. The brake function is realized by the action of the pilot turning the pedal. With the deflection of the pedal, the corresponding electrical signal is generated to control the brake of the left and right wheels. The existing brake device has large body, heavy mass and poor signal transmission linearity, which can't meet the requirements of aviation finished product design [3]. Therefore, in order to realize the lightweight, miniaturization and linearity requirements of integrated rudder pedal, it is urgent to develop a new integrated rudder pedal brake device.

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2 Mechanism Analysis of Brake Device

Figure 1 shows the mechanism of rudder pedal brake. As can be seen from Fig. 1, the pedal footboard is connected with the pedal footboard support through a dumpling chain, and the pedal footboard can burn the pedal support for rotation. A brake command sensor is installed between the pedal footboard and the pedal footboard support, measure the change of the rotation distance of the pedal footboard, generate a voltage signal and send it to the brake control box [4]. At the same time, the brake command sensor provides the pilot with brake force reaction, and ensures that the pedal footboard can return to the initial state when the pilot does not step on the pedal footboard.

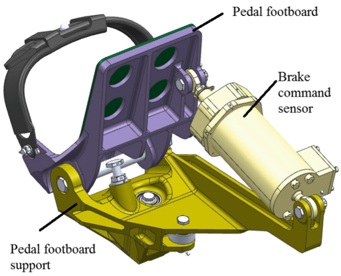

Fig. 1. Tradition structure of brake device

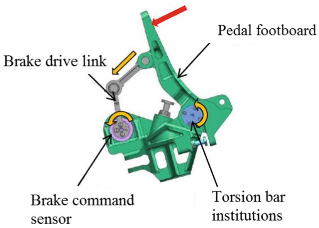

Fig. 2. Principle of brake device

At present, the brake command sensor in the form of linear spring is almost used in aircraft rudder pedal brake devices at home and abroad [5]. The installation and commissioning of this mechanism is simple, but the pedal deflection angle is directly transformed into the linear compression movement of the spring, resulting in poor linearity of brake signal transmission, complex structure of brake device, large space and heavy weight.

3 Principle of Brake Device Based on Torsion Bar

3.1 Principle of Brake Device

Figure 2 shows the principle of brake device based on torsion bar. As can be seen from Fig. 2, the weaving action of the pilot's toe pressing the pedal causes the pedal to deflect forward, and the rotation of the pedal is transmitted to the input shaft of the brake command sensor through the brake connecting rod transmission mechanism. The brake command sensor generates an output electrical signal after being sensitive to the rotation angle of the input shaft, At the same time, when the pedal rotates, it drives the torsion bar to twist and deform, resulting in a sense of brake force proportional to the weaving displacement, which is reversed to the pilot.

3.2 Torsion Bar and Supporting Mechanism

The torsion bar is an elastic straight bar, which generates torque through torsional deformation, so as to provide brake force for the pedal. The torsion bar is characterized by lightweight, simple structure and small space.

The core part of the torsion bar and support mechanism is the torsion bar, which produces torsional deformation under the action of external force, so as to provide torque. The support mechanism is designed as an empty tube (hollow shaft) to facilitate the passage of the torsion bar, and ensure that the torsion bar does not bear the bending load during the rudder process. Figure 3 shows the cross-linking relationship between torsion bar, support mechanism, pedal and pedal support.

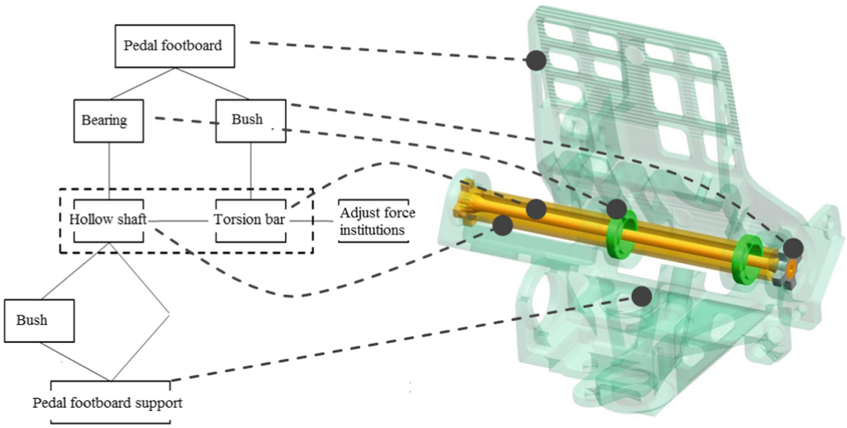

Fig. 3. Cross-linking relationship of brake device

3.3 Brake Transmission Mechanism

The brake transmission mechanism transmits the movement of the pedal to the brake command sensor, and the input shaft of the torso brake command sensor rotates. Because the torsion bar is at the rotation center of the pedal and pedal support, in order to make full use of the space of the brake mechanism, the brake command sensor is arranged parallel to the torsion bar, and the rotation of the pedal is transmitted to the input shaft of the brake command sensor through the four-bar mechanism between the pedal and pedal support. At the same time, according to the brake operation stage stroke and the effective working stroke of the brake command sensor, the rod system size of the brake connecting rod transmission mechanism is allocated, and the transmission relationship of the mechanism is obtained, as shown in Fig. 4.

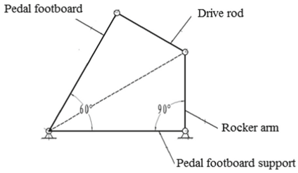

Fig. 4. Transmission diagram of brake linkage

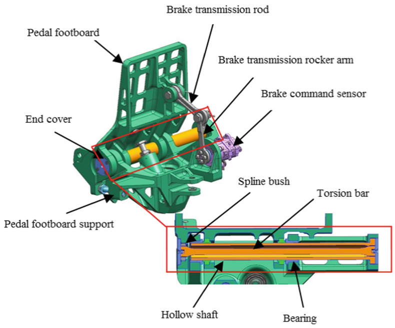

Fig. 5. Component of brake device

4 Detailed Design of Brake Device Based on Torsion Bar

4.1 Composition of Brake Device

The brake device based on torsion bar is mainly composed of pedal footboard, pedal footboard support, brake transmission rod, brake transmission rocker arm, brake command sensor, hollow shaft, torsion bar, spline bush, end cover, bearing, etc., as shown in Fig. 5.

4.2 Detailed Design of Torsion Bar and Supporting Mechanism

The torsion bar and supporting mechanism are shown in Fig. 6. The torsion bar is the core part to provide brake force for the rudder pedal brake. During the working process of the rudder pedal brake, the torsion bar is subjected to torsional load and torsional deformation occurs. At the same time, it should be avoided to apply bending load to the torsion bar during the operation of rudder and brake. The hollow shaft passes through the mounting hole on the rotation axis of the rudder pedal and supports the rudder pedal footboard. The spline end of the hollow shaft is embedded in the pedal support to fix it in the circumferential direction; The torsion bar passes through the hollow shaft, and its spline end is matched with the internal spline of the hollow shaft; The spline bush is embedded into the mounting hole of the rudder pedal footboard support, and its internal spline is matched with the spline at the end of the torsion rod; When the brake works, the pedal deflection drives the spline bush to rotate, and drives the torsion bar to rotate close to the end of the spline bush, so as to produce torsional deformation of the torsion bar and provide a sense of brake force for the pilot.

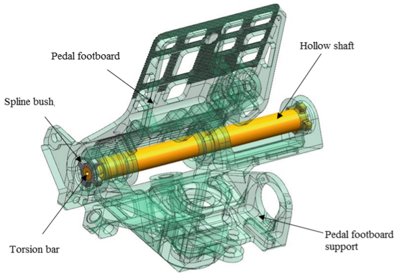

Fig. 6. Torsion bar and support structure

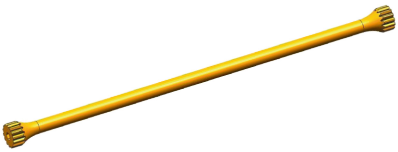

Fig. 7. Structure of torsion bar

Torsion bar is the core part to provide brake force for the rudder pedal, and its torsional stiffness and fatigue strength are very important. Considering the design, processing degree and pedal installation space, the section shape of the torsion bar structure is a solid circular straight bar, and its end (installation connection part) is an open line spline. Arc transition is selected between the torsion bar body and the end spline, as shown in Fig. 7.

The performance of torsion bar material has an important impact on the shear strength and fatigue life of torsion bar. The material parameters are obtained [6–8], as shown in Table 1.

Table 1. Material properties of elastic alloy

Material mark	Material standard	Tension strength Mpa	Yield strength Mpa	Fatigue limit Mpa	Young's modulus Gpa	Shear modulus Gpa
60Si2MnA	GB/T1222-2007	1570	1375	575	163 ~ 170	52 ~ 63

The stiffness K formula of torsion bar is:

$$K = \frac{1000\pi d^4 G}{32LT180} \tag{1}$$

where T is the torsional moment, L is the effective length of the torsion bar, d is the diameter of the torsion bar, and G is the shear modulus of the torsion bar material. Check the fatigue strength of the torsion bar, according to the fatigue limit of material mark 60Si2MnA, $\delta_{-1}= 575$ Mpa (the number of stress cycles is 10^7), so the allowable shear fatigue limit $\tau_{-1}= 0.58 \times \delta_{-1}= 334$ Mpa. It can be seen that the maximum shear stress of torsion bar is greater than the shear fatigue limit. According to the S-N curve, the calculation shows that under the maximum shear stress cyclic load, the fatigue life is far greater than the life requirements of the rudder pedal brake device.

4.3 Design of Brake Command Sensor

The brake command sensor of the brake device is a sensor sensitive to the brake weaving stroke. The brake command sensor is fixed on the rudder pedal footboard support through flange. The technical indicators of brake sensor are obtained, as shown in Table 2.

Table 2. Technical indicators of brake sensor

Serial number	Project	Index requirements
1	Excitation voltage	10V 2000 Hz
2	Electrical stroke	±40°
3	Weight	≤200 g
4	Gradient	(0.2 ± 0.01) Vrms/deg
5	Precision	≤1%F.S
6	Tracking accuracy	≤1%F.S
7	Asymmetry degree	≤0.5%F.S
8	Zero voltage	≤50 mV
9	Sum voltage	(10 ± 1) Vrms
10	Cross coupling	≤0.5%F.S
11	Phase shift	≤10°
12	Input current	≤30 mA

4.4 Kinematics Simulation Analysis of Brake Device

After the brake device is designed in detail, Simulation software is used to conduct kinematics simulation analysis of brake device [9, 10], and the results are shown in Fig. 8. According to the analysis results, the kinematic relationship between brake stroke and rotation angle of RVDT input shaft is consistent with the calculation results of theoretical design.

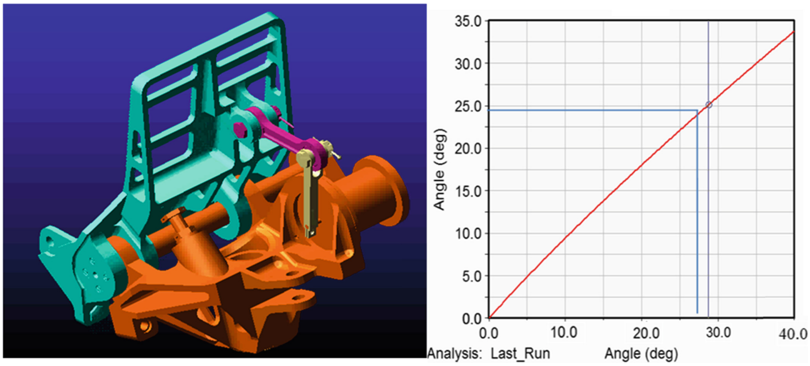

Fig. 8. Kinematics simulation analysis result of brake device

5 Weight Comparison of Brake Device

The lightweight effect of the brake device based on torsion bar is remarkable [11]. At the same time, on the premise of ensuring the strength of parts and components, the lightweight design of parts and components is carried out by optimizing the architecture design and removing redundant materials. The weight of the whole brake device based on torsion bar has been reduced considerably, and the lightweight design efficiency achieves 25%.

6 Conclusion

The integrated rudder pedal brake device based on torsion bar has been designed and verified, and applied to specific models of finished products. The practical application shows that the brake device based on torsion bar has correct principle, compact structure, high space utilization and lightweight. It solves the shortcomings of traditional brake device, such as complex structure, heavy weight and poor signal linearity. It has important engineering practical value and good economy.

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