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# A design scheme of vehicle-mounted radar tipping and lifting device

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**Abstract:** Aiming at the characteristics of compact structure, high integration and limited weight and volume of the mobile platform for vehicle-mounted high-power microwave weapon, this paper carried out an integrated design of lifting Jane and lifting electric cylinder. The performance index, system composition and structure design of the tipping lift device are described in detail. Through checking and testing the performance index, the author guarantees that the design is reasonable and feasible. The device runs smoothly after loading. This meets the functional requirements. It can be used as a reference for the subsequent development of radar overturning lifting system under similar conditions.

**Keywords:** Finte element analysis; Precision analysis; Vehicle-mounted weapon; Lifting device; Structure design; Electric cylinder

## 1. Introduction

In recent years, vehicle-mounted high power microwave weapon systems have been developed rapidly. Its maneuvering platform is mainly composed of high-power microwave weapons, radar systems, photoelectric equipment, etc. [1-4], resulting in compact structure, high integration and strong mobility. The vehicle has two states: working and transporting. When working, the high-power microwave weapon drives the photoelectric equipment to pitch and rotate to the working state. The radar needs to be flipped to working condition. At the same time, in order to avoid high power microwave weapon occlusion, the radar needs to be raised to a certain height. When the work is over, the radar is lowered to a low level and then tipped over to transport. At the same time, the high-power microwave weapon drives the photoelectric device to pitch and rotate to the transport state. This ensures that the overall size of the vehicle meets the requirements of highway and railway transportation not too high and not too wide.

The traditional tipping lifting device adopts the electric cylinder drive lifting simple mode, cylinder simple separation. The external electric cylinder will make the overall contour larger, which affects the layout of the motor platform. The electric cylinder is built in, the lifting will become thicker, which exposes the large volume, heavy weight, lack of sealing and poor environmental adaptability. This does not meet the requirements of small space layout.

In this paper, the lifting electric cylinder and lifting simple integrated design. The device has the advantages of small volume, light weight, good sealing and strong environmental adaptability. The finite element analysis of the main bearing parts is carried out by reasonably controlling the transmission accuracy of the lifting and tipping electric cylinders and the shape and position tolerance dimensions of the key parts of the tipping support. This meets the technical specification requirements of the tipping lifting device.

## 2. Technical specifications and parameters

See Table 1 for technical indexes and parameters of tipping lifting device.

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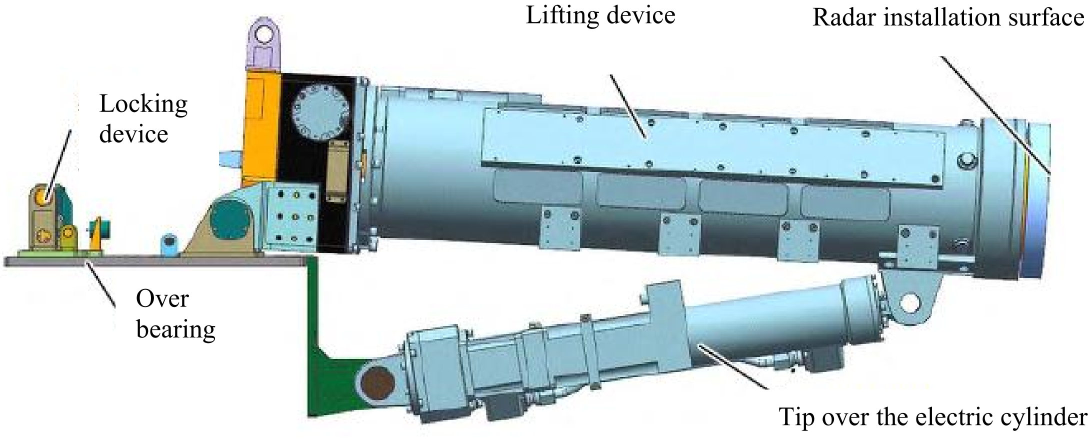
Table 1 Overturned lifting device technical indicators and parameters

| Index name | Parameter values | The test conditions |
| --- | --- | --- |
| Thrust of the lifting device /kN | 10 | - |
| Axial checking accuracy of lifting device /mm | 0.5 | An axial load of 800 kg was applied |
| Overturning electric cylinder thrust /kN | 38 | - |
| Axial checking accuracy of overturned electric cylinder /mm | 0.3 | An axial load of 300 kg was applied |
| Horizontal accuracy /(') | 3 | Apply a lateral force of 200 N |
| High torsion accuracy /(') | 3 | Apply torque of 100 N·m |

# 3. System composition and working principle

## 3.1 System Composition

The tipping lifting device is mainly composed of four parts: lifting device, tipping electric cylinder, locking device and tipping support, as shown in Figure 1.




## 3.2 Working principle

Under the drive of the tipping motor, the tipping electric cylinder can complete the turning up function in the working state and the turning down function in the withdrawing state. The tipping Angle ranges from -3° to 90°. After tipping to the working state, the safety lock is locked, and the lifting action can be performed.

After the safety lock is locked, the lifting device, driven by the lifting servo motor, lifts the radar to a high position with a lifting height of 700 mm. It is on the march, with the radar low and the safety lock unlocked. This performs the flip to transport action.

The toppling support provides a stable and reliable installation platform for the toppling lifting device. This ensures position accuracy, motion accuracy, strength, stiffness and excellent maneuverability of the radar.

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# 4. Structural design of tipping lifting device

## 4.1 Lifting device design

The lifting device (FIG. 2) has the lifting function. It is also the support platform of radar working state. The servo motor provides power for the lifting device, drives the worm gear and worm pair, the turbine drives the screw nut pair, and the secondary cylinder is fixably connected with the nut. The guide key between the primary cylinder and the secondary cylinder enables the secondary cylinder to be positioned in the circumferential direction. Under the drive of the lead screw, the upward lift is realized. The four guide keys are symmetrically distributed, which not only play a guiding role, but also can bear the radial load. Reasonably control the straightness of keyway and the fit gap between key and slot. This ensures the repeatable positioning accuracy of the lifting device and the stability of radar operation.

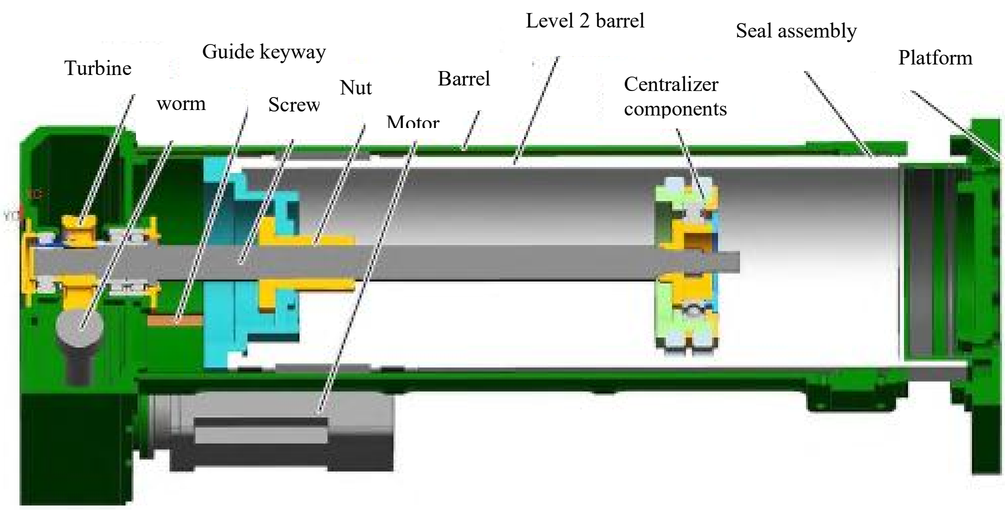


Figure 2 lifting device schematic diagram

The lifting device is an integrated cylinder design. The outer cylinder of the electric cylinder is the first cylinder of the lifting device, with a diameter of 240 mm. The push rod of the electric cylinder serves as the bipolar cylinder of the lifting device, with a diameter of 179 mm. The flange diameter of the radar mounting platform is 230 mm, the closure size is 1130mm, the effective stroke is 700 mm, and the total mass is about 195 kg. The lifting device with integrated cylinder design is compact in structure, small in volume and light in weight (about 60kg lighter than the cylinder split design).

The simple wall sealing assembly of the lifting device adopts the structure of O-ring and guide ring with double and directional retaining rings for shaft sealing, as shown in Figure 3. The application of this structure in oil cylinder and electric cylinder has been mature. It has good waterproof and dustproof performance and dynamic and static sealing characteristics, and the friction is small, long life.


Figure 3 Seal assembly structure diagram

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### 4.2 Overturned electric cylinder design

The overturned electric cylinder is a mature electric cylinder, and its appearance is shown in Figure 4. It will not be expanded here to describe its detailed design. The servo motor provides the power to tip over the electric cylinder. The motor lock can realize self-locking after tipping in place. The limit switch ensures the safety of the overturning electric cylinder and reasonably controls the axial movement of the push rod. This ensures the stability of radar operation. The outer diameter of the cylinder is 90mm, the diameter of the push rod is 63mm, the closing size is 786mm, the effective stroke is 460 mm, and the total mass is about 60 kg.

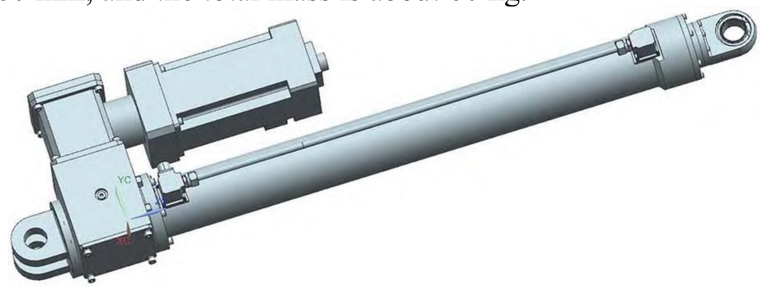

Figure 4 Overturned electric cylinder shape figure

### 4.3 Toppling support design

### 4.3.1 Topple support structure design

The overturning support comprises an installation base plate, an overturning cylinder installation seat, a lifting cylinder installation seat, a safety lock and a limit switch. The bottom plate and one side of the toppling support are fixed with the maneuvering platform. The toppling support provides a supporting platform for the toppling lifting device. After the 90° limit switch detection is turned in place, the safety lock is locked and the radar can implement target detection. When withdrawing, -3° limit switch detects whether the withdrawal is in place. The shape of the toppling support is shown in Figure 5.

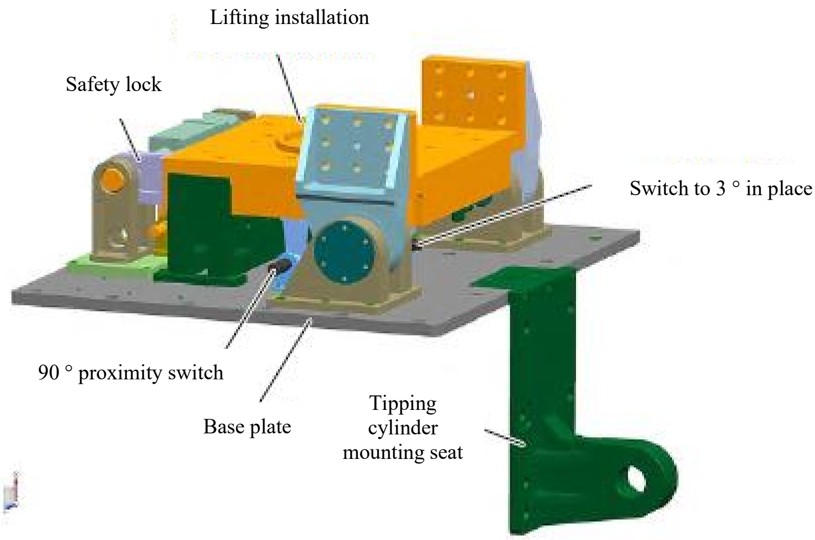


Figure 5 Overturned bearing figure shape

### 4.3.2 Rainfall distribution on 10-12 overturned bearing finite element analysis

In the initial stage of lifting device, the toppling support load is maximum. At this time, the thrust of the overturned electric cylinder is 38000N. The bottom plate and the support on the bottom plate are connected through the stop interference and fixed with screws. The mounting support of the lifting device and the lug are also connected through the stop interference and fixed with screws. According to the product installation conditions, fixed constraints are imposed on the installation surface under the bottom plate and the installation surface on the left side of the overturned electric

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cylinder support. Face-to-face bonding is defined at the interference connection surface, and face-to-face contact is defined at the pin shaft. According to the 38000N load, the pressure is applied at the rotating shaft of the support under the overturned electric cylinder, and the tension is applied at the mounting seat of the lifting device to carry out the statics simulation. The maximum Von-Mises yield stress was 192.24 MPa, which appeared on both sides of the pin hole of the lower support of the overturning cylinder. The lower support material is 40Cr material. First, the yield strength is 784 MPa, the design margin is 3.1, and the shear stress of the lower bearing pin is 49.25 MPa. Second, the shear strength is 0.5 times the yield strength, and the design margin is 7.1. They all meet the mechanical design requirements. FIG. 6 shows the stress cloud diagram of the overturned support of the lower support. The stress value of each part is extracted and the design margin is calculated. The results are shown in Table 2. All these meet the requirements of mechanical design

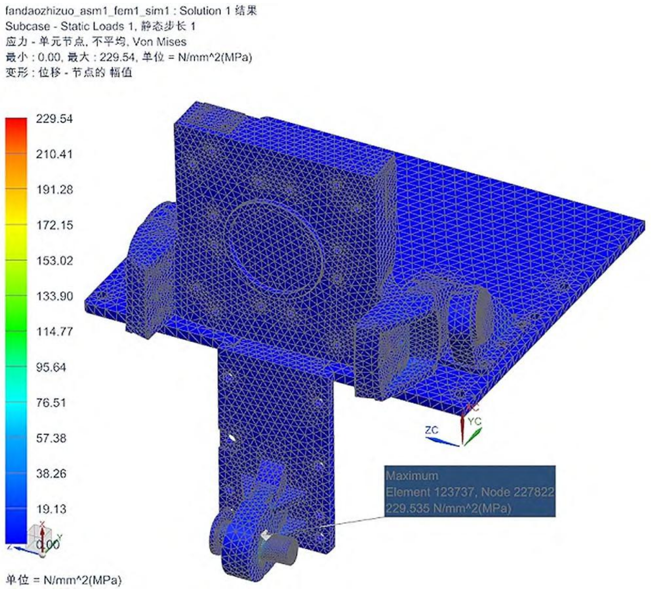

Figure 6 Bearing stress nephogram

Table 2 Overturned stress table bearing parts

| Name | Material | Yield strength /MPa | Simulation results /MPa | Design margin |
|---|---|---|---|---|
| Base plate | 40Cr | 784 | 45.36 | 16.3 |
| Upper support of bottom plate | 40Cr | 784 | 58.11 | 12.5 |
| Lifting drum mounting seat | 7075-T6 | 445 | 56.35 | 6.9 |
| Install the seat lug | 40Cr | 784 | 50.35 | 14.6 |
| Trunnion | 40Cr | 784 | 96.56 | 7.1 |
| Overturn cylinder support | 40Cr | 784 | 192.24 | 3.1 |
| Bearing shaft | 40Cr | 784 | 85.33 | 8.2 |

## 5. Check the technical index of tipping lifting device

### 5.1 Axial channeling accuracy of overturning electric cylinder

The axial movement of the overturning electric cylinder is mainly caused by the return difference of the drive chain of the reducer of the electric cylinder and the travel variation in the effective travel of the ball screw pair [5]. Among them, the back difference of the drive chain of the

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overturned electric cylinder includes two parts: the standard reducer and the drive chain difference of the reversing gear pair.

### 5.1.1 Caused by reducer return difference axial momentum

A planetary reducer with a reduction ratio of 32:1 is selected for the overturned electric cylinder. The reducer model is KPX085-32. Return clearance ≤ 8 '. The calculation formula of the axial crossing momentum SF1 of the overturned electric cylinder caused by the reducer back difference is:

$$S_{F_1} = \frac{\Delta/60}{360} P_h \qquad (1)$$

Where, A is the reducer back difference clearance,('), P is the lead of the lead screw,mm. Calculation:

$$S_{F_1} = \frac{8/60}{360} \times 10 = 0.0037\ \mathrm{mm} \qquad (2)$$

### 5.1.2 Return difference caused by the reverse gears transmission chain of axial momentum

The reversing gear pair of inverted electric cylinder is a pair of involute spur gear. The transmission ratio is 1.4:1. The machining accuracy of gear pair is 7 grade. According to its structure size and precision grade, the maximum value of the transmission chain back difference is 10.5'. The calculation method of the axial channeling momentum SF2 caused by it is the same as that of SF1. The calculation results are:

$$S_{F_2} = \frac{10.5/60}{360} \times 10 = 0.0048\ \mathrm{mm} \qquad (3)$$

### 5.1.3 Ball screw vice schedule changes within the effective stroke volume

The travel variation in the effective travel of the ball screw pair of the overturned electric cylinder will directly lead to the axial movement of the overturned electric cylinder. The machining accuracy of ball screw pair is P7. The lead accuracy per 300mm stroke is 0.052mm. The total stroke of tipping electric cylinder is 460 mm. Its effective stroke within the stroke variation SF3 is 0.08mm.

Overturned electric cylinder axial channeling dynamic precision of the SF for:

$$S_F = \sqrt{\frac{\sum_{i=1}^{n} S_{F_i}^2}{n}} \qquad (4)$$

Where, SFi is the axial channeling momentum affecting the overturned electric cylinder,mm,n is the number of affected items.

Calculation:

$$S_F = \sqrt{\frac{S_{F_1}^2 + S_{F_2}^2 + S_{F_3}^2}{3}} = 0.0463\ \mathrm{mm} \qquad (5)$$

Axial channelling accuracy of overturned electric cylinder ≤0.3mm, the design meets the requirements.

### 5.2 Axial channeling accuracy of the lifting device

The axial movement of the lifting device is mainly caused by the return difference of the gearbox transmission chain and the travel variation in the effective travel of the ball screw pair. Among them, the transmission chain back difference of the lifting device includes reversing reducer and worm gear reducer transmission chain back difference of two parts.

### 5.2.1 Axial channeling momentum caused by reversing reducer back difference

A bevel gear commutator with a reduction ratio of 1:1 is selected for the lifting device. The model number is KVX065-1. The return clearance is ≤6 '. The calculation method of the axial

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channeling momentum SJ1 of the lifting device caused by the reducer back difference is the same as that of SF1. The calculation results are:

$$S_{J_1} = \frac{6/60}{360} \times 8 = 0.0022\ \mathrm{mm} \qquad (6)$$

### 5.2.2 Axial channeling momentum caused by the back difference of worm gear and worm reducer

The two-stage deceleration of the lifting device adopts worm gear and worm drive, and its deceleration ratio is 42:1. The machining accuracy of worm gear and worm gear pair is level 7. According to the structure size and accuracy level, the return clearance is ≤ 3.4'. The calculation method of axial channeling momentum SJ2 caused by it is the same as that of SF1. The calculation results are:

$$S_{J_2} = \frac{3.4/60}{360} \times 8 = 0.0013\ \mathrm{mm} \qquad (7)$$

### 5.2.3 Travel variation in effective travel of ball screw pair

The machining accuracy of the ball screw pair of the lifting device is P7, the lead range of each 300 mm stroke is 0.052mm, and the total lifting stroke is 700 mm. The stroke variation Sj3 within its effective stroke is 0.12mm.

The axial channeling accuracy SJ of the lifting device is:

$$S_J = \sqrt{\frac{S_{J_1}^2 + S_{J_2}^2 + S_{J_3}^2}{3}} = 0.0693\ \mathrm{mm} \qquad (8)$$

Axial channeling accuracy of lifting device ≤0.5mm, the design meets the requirements.

### 5.3 Reverse accuracy overturned lifting device

The high torsion accuracy of the overturning lifting device directly affects the pointing accuracy of the radar. The main factors affecting the torsion accuracy of the inverted lifting device include the clearance of the rotating shaft, the wind load and centrifugal load of the antenna, and the clearance between the guide key and the keyway of the lifting cylinder.

When designing the product, the pin and the hole at the shaft are made of the base hole, and the pin is designed in series, that is, the pin with different diameters is adapted on site. When assembling, apply lubricating oil to the pin and hole, and then knock moderately with the wood coconut head, and load. This ensures zero clearance fit and eliminates the impact of clearance at the rotating shaft on the torsional accuracy of the tipping lift device.

After the antenna assembly is completed, the operation balance test and trimming are required. This ensures that the center of mass of the antenna is located at the center of the rotating axis, and no centrifugal force is generated during the antenna rotation. It eliminates the influence of eccentric load caused by centrifugal load on the torsional accuracy of tipping lift device.

The precision wind speed of the product is level 8 wind, the wind speed is 20 m/s, the characteristic size of the antenna array is 750mmx 850 mm, and the maximum load torque of the calculated wind is 54 N·m. Through simulation calculation (100 N-m torque is applied during simulation), the torsional deformation of lifting cylinder caused by wind load torque is small and can be neglected.

When the lifting cylinder lifts, the keyway guide between the push rod and the outer cylinder limits the rotation of the push rod to achieve lifting. The center circumference of the keyway is 93.5mm, the clearance between the key and the slot ≤0.08 mm. Calculated according to the maximum clearance, the torsion Angle $\theta$ is:

$$\theta = \arctan \frac{\delta}{R} \qquad (9)$$

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Where, $\delta$ is the gap between key and slot, mm. R is the circumference radius of key groove center, mm.

Calculation:

$$\theta = \arctan \frac{0.08}{93.5} = 2.94' \tag{10}$$

The torsion accuracy of the toppling lift device is not more than 3'. The design meets the requirements of technical indicators.

### 5.4 Thrust lifting device check

The rated torque of the lifting servo motor is 3.5N ·m, the reduction ratio is 42:1, the lead screw lead is 8mm, and the transmission efficiency is 0.15. According to formula (11) [6], the thrust force F of the lifting device can be calculated as follows:

$$F = \frac{T\eta 2\pi n}{P_{\mathrm{h}}} \tag{11}$$

Where, T is the rated torque of the motor, N·m. η is the transmission efficiency.

Calculation:

$$F = \frac{3.5 \times 0.15 \times 2 \times 3.14 \times 42}{8} = 17\ \mathrm{kN} \tag{12}$$

Lifting device design index requirements thrust >10 kN. The checking result meets the requirement of design technical index.

### 5.5 Overturned electric cylinder thrust respectively

The rated torque of the motor is 3.5N ·m, deceleration ratio is 44.8:1, lead screw lead is 10 mm, and transmission efficiency is 0.65. Put it into Equation (11) to calculate the thrust force F of the overturned electric cylinder:

$$F = \frac{3.5 \times 0.65 \times 2 \times 3.14 \times 44.8}{10} = 64\ \mathrm{kN} \tag{13}$$

Overturning electric cylinder design index requirements thrust >38 kN. The checking result meets the requirement of design technical index.

### 5.6 Overturned lifting device level precision analysis

The horizontal accuracy of the overturning lifting device is mainly caused by the axial movement of the overturning electric cylinder. According to the calculation in Section 4.1, the axial channelling momentum of the overturned electric cylinder is 0.0843mm. According to the distance relationship between the three rotating shafts of the tipping lifting device, the levelness error is calculated as 45". The design accuracy meets the requirement of technical index.

## 6. Index test of tipping lifting device

### 6.1 Test Methods

#### 6.1.1 Thrust test

The lifting device and the tipping electric cylinder are successively connected to the test rack of the T50 test bed. Apply axial thrust load (radial righting) according to the technical index value. Driven by the debugging motor, the lifting speed is 5 m/s, lifting 3 times. This requires smooth operation, no stuck stagnation, channeling, crawling and other abnormal phenomena.

#### 6.1.2 Axial channeling test

The lifting device and the tipping electric cylinder are placed horizontally and fixed successively, and the inlet of the reducer is fixed. The load values required by technical indicators are applied

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along the axial direction and the reverse direction, and the axial displacement change of the push rod is the axial channeling value.

### 6.1.3 Horizontal accuracy test

Tip the tipping lifting device to working condition. Image level is placed on the radar mounting platform. And the thrust value required by the technical index is applied in the positive and reverse direction. The variation of image level is the horizontal precision value.

### 6.1.4 Torsion accuracy test

Tip the tip lift to level. The secondary cylinder extends 700 mm. The radar mounting platform is horizontally fixed on the crossbar. The tipper is placed on the upper end of the crossbar, and the torque is calculated by hanging the weight in the front and back through the hole on the crossbar. When the calculated torque reaches the required value of the technical index, the change of the tipper is the value of the torsion accuracy.

### 6.2 Test Results

After the assembly of the toppling lifting device, the technical indexes were measured. The results are shown in Table 3.

Table 3 Index test table

| Index name | Technical indicators | Design value | Test values |
|---|---|---|---|
| Thrust of the lifting device /kN | 10 | 17 | 10 |
| Axial channeling accuracy of lifting device /mm | 0.5000 | 0.1265 | 0.2800 |
| Overturning electric cylinder thrust /kN | 38 | 64 | 52 |
| Overturning electric cylinder axial channeling accuracy /mm | 0.3000 | 0.0843 | 0.2800 |
| Horizontal accuracy /(') | 3.00 | 0.75 | 2.60 |
| Torsion accuracy /(') | 3.00 | 2.94 | 1.80 |

## 7. Conclusion

According to the characteristics of compact structure, high integration and limited weight and volume, the mobile platform of vehicle-mounted high power microwave weapon is presented in this paper. This developed a set of cylinder integrated tipping lifting device for radar. This paper introduces the technical index of the tipping lift device. According to the technical indexes, the overall structure design of the tipping lifting device is completed and the technical indexes are checked. The result meets the requirements. Through the finite element simulation analysis of the overturning support, the sufficient strength and stiffness are guaranteed. This provides a reliable and stable platform for the radar system. After the assembly, the technical indexes were measured. The results meet the design requirements. The device has been put into engineering application and its performance is stable. The development mainly solves the design problems of miniaturization, lightness and tightness, which lays a foundation for the subsequent performance verification of radar system

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