Structural design of wind turbine tower climbing robot

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Abstract. This paper combines the actual needs of the structure design of the climbing robot, uses the three-dimensional software to virtual design the mechanical structure, and performs finite element simulation on the key components to verify the reliability. On this basis, the components with higher quality are Topology optimization reduces weight without reducing stiffness, enabling lightweight design and improved overall performance. Through the structural design of the robot, the overall layout of the robot is functional. Important parts such as the body, power system, and mobile system are designed in detail, and the physical parts of the prototype are processed. Converting the roll cage design in the racing field into the body design of the robot to increase the rigidity of the body.

1. Introduction
Structural design is an important part of the product development process. The result of structural design is the premise of product trial production, and also the basis of the robot. This paper combines the actual needs to carry out the structural design of the climbing robot, and uses the three-dimensional software to virtual design the mechanical structure. The finite element simulation of the key components is used to verify the reliability. On this basis, the topological optimization of the components with higher quality is carried out, the weight is reduced without reducing the rigidity, the lightweight design is realized and the performance of the whole machine is improved.
The overall mechanical structure of the tower climbing robot is modelled and rendered by solid works. The three-dimensional model is shown in Figure 1. The robot consists of five parts: the main part, the external system, the bilaterally symmetric mobile system, the power system and the adsorption unit. The power system components such as electrical equipment and motor are arranged in the main part, and the mobile system is composed of a support frame, a timing belt, a synchronous wheel, etc., and the external system can be replaced as required. The adsorption unit is evenly arranged on the outermost side of the synchronous belt in the mobile system, in direct contact with the wall.

2. Design of the main part of the climbing robot

2.1. Climbing robot body internal layout

The main body of the climbing robot is shown in Figure 2. The main part of the robot is composed of a frame, a motor, a reduction box, a power supply, an electric control system, and the like, which are composed of two side plates, a bottom plate, a top plate and a reinforcing rod, and the front side expansion bin is used for subsequent expansion.

![Figure 2. Climbing robot body layout](image)

The bottom plate, the side plates and the reinforcing rods form a stable frame by bolt connection. The lower the center of gravity of the robot, the stronger the anti-overturning ability, so the heavier power supply is arranged in the bottom reinforcement rib, and the same motor is arranged on the rear side. The front side can reduce the overturning moment, so the driving mode is that the rear wheel drive takes into account the lightweight design, and the secondary reduction gearbox is directly designed to be integrated with the side plate. The lighter electrical components are arranged in the upper middle layer. Because the sensors are mainly arranged on the front side, in order to reduce the signal transmission distance and improve the anti-interference ability, the signal processing center is arranged in the front part of the robot body. The control part of the vehicle body and the signal transmission center are arranged in the middle. Because the motor drive generates a large amount of heat, it is disposed separately beside the motor and in contact with the wall surface of the side plate to improve the heat dissipation capability.
2.2. Climbing robot body design

The main body of the robot is connected to the mobile system and the external system, and carries various electrical components. Therefore, the rigidity of the vehicle body is required and the internal electrical components can be protected.

As shown in Fig. 3, the main body of the robot adopts a cage design, a load-bearing body, and a reinforcing rod inside to improve the rigidity of the body.

![Figure 3. Climbing robot body](image1)

As shown in Figure 4, reference is made to the design of the roll cage used in the WRC and road racing cars and the ribs in the car design. The design of the reinforcing rod is added to the robot. The introduction of the reinforcing rod can greatly improve the rigidity of the body while ensuring that the main body is light. Can play a certain role in dividing the space inside the main body, to facilitate the fixing of parts.

![Figure 4. Road racing roll cage](image2)

3. Climbing robot power system

The climbing robot power system adopts the double motor wheel side drive mode. The power transmission route is shown in Figure 3.5. The motor power is transmitted to the timing belt via the planetary reduction gear box, the wheel side reduction gear box and the synchronous pulley.
The robot mainly walks on the outer wall of the tower, which requires high driving torque and stability. Therefore, the selection of the drive motor and the design of the reduction gearbox are the focus.

3.1. Selection of drive motor

Total load $F_{max}=900n$, the highest crawling speed $V_{max}=5m/min$, the effective power required to drive the robot is

$$P_w = F_{max} \times V_{max} = 900 \times 5 / 60 = 75W$$

Drive system efficiency is

$$\eta_{total} = \eta_r \times \eta_l \times \eta_d$$

In the middle $\eta_r$—the efficiency of the planetary gearbox, take $\eta_r=0.9$

$\eta_l$—the efficiency of the wheel reducer, take $\eta_l=0.95$

$\eta_d$—the efficiency of the belt drive, take $\eta_d=0.9$

Therefore

$$\eta_{total} = 0.9 \times 0.95 \times 0.9 = 0.77$$

Then the motor power is

$$P_e = \frac{P_w}{K_s \eta_{total}} = \frac{75}{0.9 \times 0.77} = 108W$$

The relevant calculation formula for the traction force of the robot is matched with the motor of the different hollow cup gearbox in Table 1 (excerpt). Finally, considering the parameters such as torque and speed, jgb37-550-12V-295 is selected as the final drive system. Drive the motor, the physical object is shown in Figure 6.

| Geared motor model | JGB37-550-12V-125 | JGB37-550-12V-295 | JGB37-550-12V-688 |
|-------------------|-------------------|-------------------|-------------------|
| Voltage (v)       | 12                | 12                | 12                |
| No-load speed (rpm)| 125               | 295               | 688               |
| No-load current (a)| 1.6               | 1.6               | 1.6               |
| Load speed (rpm)  | 105               | 250               | 585               |
| Rated torqueKg? cm| 25                | 12                | 9                 |
| Power (w)         | 60                | 60                | 60                |
| Load current (a)  | 1.5               | 2                 | 2.5               |
| Stalling torqueKg cm| 120              | 80                | 55                |
| Stall current (a) | 7                 | 7                 | 7                 |
| Reduction ratio   | 1:131             | 1:56              | 1:24              |
| Reduction box length (mm) | 31        | 27                | 24                |
| Weight (g)        | 320               | 300               | 288               |
3.2. Wheel reducer design
Because the wall-climbing robot has higher requirements on the output torque, it needs to add one more deceleration. The internal space of the main body of the robot is limited. In order to shorten the axial dimension of the transmission, the structure of the reduction box is designed as a wheel-side reduction box combined with the side wall. The installation position is as shown in Fig. 7a, and the two gears are respectively 1 mold 20 teeth and 1 mold 30 teeth. The gear shaft is supported by thin-walled bearings with a reduction ratio of 2:3.

Figure 7a. Gearbox mounting position

Considering the processing technology, the specific structural size parameters of the internal structure design of the gearbox housing are shown in Figure 7b. The material is 6061 aluminium alloy, and the inner minimum fillet is R2.
Mobile system design for climbing robots

The three-dimensional assembly model of the walking mechanism of the climbing robot is shown in Fig. 8, and the specific structural design of each part is as follows.

The combination of the synchronous wheel and the timing belt has a great advantage in the weight of the timing belt compared to the combination of the track and the sprocket. The key point is the synchronous wheel design, which must ensure the degree of meshing as well as its own strength.

Combined with the calculation and analysis in Chapter 2, the HTD 8M timing belt was selected. The timing belt has a bandwidth of 50 mm, a pitch of 8 mm and a belt length of 960. The physical object is shown in Figure 9.
5. Adsorption design of climbing robot

The NdFeB permanent magnet of the synchronous belt size selection grade N35 is an adsorption unit, and its appearance is shown in Fig. 12. Its chemical formula is Nd2Fe14B, which is an artificial permanent magnet and adopts an injection molding process. The parameters of the adsorption unit are shown in Table 2.
The adsorption units are evenly arranged on the timing belt at intervals of 50 mm. As shown in Fig. 13, at any time, more than 8 adsorption units on one side are in contact with the wall surface.

### Table 2. Adsorption unit parameters

| Project                  | Parameter                      |
|--------------------------|--------------------------------|
| Magnet grade             | N35                            |
| Residual magnetic induction | 11.7-12.1Kg                   |
| Coercivity               | ≥10.9kOe                       |
| Intrinsic coercivity     | ≥12kOe                         |
| Maximum magnetic energy product | 33-36 MGOe                    |
| Surface coating          | NiCuNi                         |
| Weight                   | 19g                            |
| Vertical suction         | 8.70kg                         |
| Surface magnetic field   | 3.099Gs                        |
| Operating temperature    | Less than 80°C                 |
| Size                     | Length 50* width 10* thickness 5mm, hole M4 |

### 6. Summary

In this paper, the structural design of the robot is developed, and the overall layout of the robot is performed. Important parts such as the body, power system, and mobile system are designed in detail, and the physical parts of the prototype are processed. Converting the roll cage design in the racing field into the body design of the robot to increase the rigidity of the body. The overall size of the robot is shown in Figure 13.
Figure 13. Overall size of the robot

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