Research and design of jumping mechanism of jumping robot

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Abstract: Considering the research of mechanical knowledge and robotics, a robot with bouncing leg energy storage autonomous movement is designed to realize periodic jumping. The robot combines the spring energy storage process and the jump release process and uses the missing gear to achieve the ability of the jumping robot to complete a periodic stable jump. At the same time, it has long-term battery life, allowing it to overcome obstacles that are several times its own height.

1. Introduction
In recent years, robot research has become a hot spot in the field of intelligent research. Wheeled and tracked robots can only work on flat terrain. Walking and crawling robots can only do a straight-line crawling gait, but they are weak to deal with higher obstacles or ditches. The bouncing robot can jump over obstacles and ground ditches, which can make up for the functional requirements of all terrain robot through such terrain.[1-2][3-4][5-6]

2. Design schemes
The design of jumping mechanism of jumping robot adopts intermittent jumping mode. The jumping mechanism adopts power device, stores energy through machinery and spring, and controls its release. The released elastic energy drives the whole robot to jump into the air, and completes periodic jumping through the action of missing gear.

3. Working principle
The bouncing mechanism is composed of spring energy storage device and intermediate connecting rod device. The motor drives the missing gear and spring to complete the bouncing action.

The pulley coaxial with the pinion rotates when the gear meshes with the missing gear. At the same time, the wire rope connected to the pulley is to be shortened while the upper plate of the mechanism moves down along the two cylindrical rods. It results in the changes of the positions of the four connecting rods. In addition, the spring is stretched and deformed when the elastic potential energy is retained. When the gear is separated from the missing gear, the spring starts to contract violently from the tensile state, and transfers the force to the upper platen through the connecting rod to make it accelerate upward to release the elastic potential energy of the spring, so as to achieve the upward movement of the mechanism and complete the jumping work. The whole mechanism realizes
continuous and intermittent jumping effect under the action of missing gear. The mechanism is shown in Figure 1.

![Figure 1 bounce mechanism](image1)

1-Upper plate; 2 - cylindrical rod; 3 - connecting rod; 4 – spring; 5 - spur gear; 6 – pulley; 7 - missing gear; 8 - motor and base; 9 – shaft; 10 – baffle; 11 - main shaft

Energy storage and release process: in order to control the energy release of the mechanism, a gear missing mechanism is adopted. When two gears are meshed, the whole mechanism is in the state of energy storage. When the big gear turns to the position of missing teeth, the small gear and the big gear are out of mesh and no longer mesh. At this time, the force controlling the spring in the stretching deformation state will disappear instantly, and the spring will return to the original state of maintaining the balance of the mechanism. In this process, the spring will give the connecting rod a force to move inward, and at the same time, the upper platen will move upward along the two cylindrical rods, so as to drive the whole mechanism to move upward and complete the bouncing action.

Gear transmission process: the two ends of the motor drive two gears, as shown in Figure 2. Two shafts extend out at both ends of the motor, and the power is transmitted to the pulley through two pairs of missing gear and spur gear, and the pulley is respectively wrapped with steel wire rope and connected with the upper plate. When the motor rotates, two pairs of gears are meshed to drive, the transmission shaft drives the pulley to rotate, and the wire ropes at both ends drive the upper plate to move down at the same time, so as to meet the design requirements. This design can keep the stress direction of the wire rope vertical. Can better maintain the balance of the mechanism, but also to complete the whole design needs to achieve the purpose.

![Figure 2 transmission system diagram](image2)

1-Motor; 2 - missing gear; 3 - spur gear; 4 – pulley
4. Design of energy storage spring

This paper analyzes and studies the bouncing mechanism from the structure and bouncing process of the bouncing robot, and establishes the calculation model diagram, as shown in Figure 3.

![Figure 3 jump calculation model](image)

If the total energy of the whole jumping device remains unchanged before and after taking off, the spring coefficient can be obtained from equation (1)

\[ k = \frac{m_1 gh_1 + \frac{1}{2} k \Delta x^2 \eta}{m_1 g (H + h_2) + m_2 g H} \]  

Where:
- \( m_1 \): Mass of upper slider, 0.5kg;
- \( m_2 \): Mass of lower slider is 1.65kg;
- \( h_1 \): The height of the front four-bar linkage released by the device is 75mm;
- \( h_2 \): The height of the four-bar linkage after the device is released is 190mm;
- \( H \): The jumping height of the device is 1000mm;
- \( k \): Spring coefficient;
- \( \Delta x \): Spring elongation, 97mm;
- \( \eta \): Spring efficiency, 0.9

The spring coefficient is 2.55n/mm because double springs are used in the bouncing device \( k \)

According to equation (2), the maximum load of spring is \( F_{max} = 272.85N \).

\[ F_{max} = k (\Delta x + 10) \]  

Where:
- \( F_{max} \): Maximum load of spring
- \( K \): Spring coefficient;
- \( \Delta x \): Spring elongation

Through the analysis of the spring working load, the spring of the bouncing mechanism belongs to class III load spring, and the tension spring is 1 III type C grade carbon spring steel wire is selected with a tensile strength of 760Mpa.

4.1 Calculation of spring wire diameter

According to equation (3), the curvature coefficient \( K \) is 1.18; According to equation (4), the diameter of spring wire is 2.94mm, and the standard value is 3mm. Other main dimension parameters of spring are shown in Table 1.

\[ K = \frac{0.615}{C} + \frac{4e-1}{4e-4} = 1.18 \]  

Where:
- \( C \): Winding ratio
\[
    d = 1.6 \sqrt{\frac{k C E_{\text{max}}}{[\tau]}}
\]

Where:

| Table 1 main dimension parameters of spring |
|--------------------------------------------|
| parameter                              |                |
| Diameter of spring wire (mm) \(d\)   | 3              |
| Spring outer diameter (mm) \(D_2\)    | 27             |
| Middle diameter of spring (mm) \(D_2\)| 24             |
| Spring inner diameter (mm) \(D_1\)    | 21             |

4.2 Calculate the effective working turns \(n\) of spring
According to the formula (5), the effective number of working turns \(n\) is 20.57, taking 21 as the value, and considering that both ends are tightly connected, the total number of turns \(N_1\) is 23.

\[
    N = \frac{G d^4 \Delta x}{B F D_2^3} = 20.57
\]

Where:
- \(G\)-shear modulus of spring material, 79000Mpa

4.3 Determination of deformation
Considering that this is a tension spring, the ultimate load of the spring is 341.06N according to equation (6)

\[
    F_{\text{lim}} = \frac{F_{\text{max}}}{n}
\]

Where:
- \(n\)-Safety factor, 0.8
- Since the number of working turns is changed from 20.57 to 23, the deformation and limit load of the spring are changed accordingly. According to equation (7), the elongation is 135.57mm.

\[
    \lambda_{\text{lim}} = \frac{8 n F_{\text{lim}} C^3}{G d}
\]

4.4 Calculate the spring pitch \(P\), free length and unfolding length
The distance between two adjacent circles under the action of \(F_{\text{lim}}\) \(\delta \geq 0.1d\) Then the pitch \(P\) under no load is 10.89 Mn according to formula (8)

\[
    p = d + \frac{\lambda_{\text{max}}}{N_1} + \delta
\]

According to formula (9), the free length \(L_0\) of spring is 254.976 mm, which is taken as 255 mm.

\[
    L_0 = N_1 p + 1.5d
\]

According to the formula (10), the helix angle of the spring under no load is 8.29, which meets the requirements \(\gamma = 5^\circ \sim 9^\circ\) The scope of the project.

\[
    \gamma = \arctg\frac{p}{\pi D_2}
\]

By formula (11) The unfolding length of the spring wire is obtainedLby1751.32mm

\[
    L = \frac{\pi D_2 N_1}{\cos \gamma}
\]
4.5 Calculation of spring stiffness

\[ K_p = \frac{Gd^4}{8D^3N_t} \] (12)

By formula (12), when the total number of spring turns is 23, at this time, the spring stiffness \( K_p = 1.77 \text{N/mm} \).

4.6 Stability calculation

The spring adopts two fixed supports

\[ b = \frac{L_a}{D_2} < 5.3 \]

According to formula (11), the stability \( B = 10.625 \), so it is necessary to check the stability according to formula (13),

\[ F_c = C_u K_p L_0 > F_{lim} \] (13)

Where:
- \( F_c \)-Critical load at steady state
- \( C_u \)-Coefficient of instability 0.03

The critical load \( F_c \) is 13.54n, which is less than the maximum working load of the spring. Therefore, the guide rod must be installed in the spring structure design, and the recommended clearance between the guide rod and the spring is 3-4mm.

5. Summary

Using jumping motion mode to move forward can effectively improve the robot's autonomous motion ability, strengthen the robot's terrain adaptability, and expand the application scope of autonomous motion robot. Although the hopping mechanism of hopping robot is designed and studied in this paper, there is still a lot of work to be further studied because the hopping robot is involved in many fields, such as Electromechanical, control, dynamics and kinematics analysis.[7-8][9-10]

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