Design and analysis based on RecurDyn of the electric crawler type remote controlled hedge trimmer

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Abstract. The electric crawler type remote controlled hedge trimmer is designed to reduce the emission and change the present status that hedges on the both sides of the highway are trimmed manually, which wastes much time and increase the labor costs. The hedge trimmer is designed in this article according to the working conditions and objects; the author analyses its dynamic stability in the typical working environments by RecurDyn. And the research indicates that the electric crawler type remote controlled hedge trimmer has the reasonable design to perform a great dynamic stability.

1. Introduction
With the advance of the economy in China, the demand of the energy and the quick response logistics is increasing in various fields, which lead to the rapid growth of constructing the high-speed road and its green belt [1]. Therefore, the electric crawler type remote controlled hedge trimmer is designed to reduce the emission and change the present status that hedges on the both sides of the highway are trimmed manually, which wastes much time and increase the labor costs. The author introduces the hedge trimmer in this article and analysis its dynamic stability to make sure that the hedge trimmer could finish the work.

2. The digital design of the hedge trimmer

2.1. Working condition and working objects
The road slope is a natural and man-made gradient structure on the both side of the roadbed to guarantee the stability of the road. And the ratio of the slope where the hedge trimmer could working is 1:1.5-1:2. According to the local climate, people grow different plants to green the road slope [2], for example in the north of China, the common types of plants are arbor-shrub, shrub, shrub-lawn and herbage, and these stems are either flexible or stout. Therefore, the hedge trimmer should have enough rotational velocity and torque to finish the trimming work [3].

2.2. Establishment of the 3D model
This design has the double-tracked chassis structure, the multi-motor driver and the front arrangement of the tools, and details are shown in the Figure 1. And some important parameters are as follows: the weight of the vehicle is 3t; the external size (length * width * height) is 3500mm * 1650m * 1200mm; the ability of the climbing slope is 30°; the speed is 3km/h in working and 2km/h in climbing; and the cruise duration is 4h in theory.
This vehicle has rubber track, which could not only save the costs, but reduce its weight, and enhance the interchangeability [4]; the main structure of the chassis contain four type of crawler wheel, which are driving wheel, guide pulley, tract roller and carrier roller; and the auxiliary structure are track adjuster, track frame and so like. The structures mention above are the typical track design for such machine on construction machine and the garden machine to work well in the harsh working environment [5]. The parameters of the vehicle are shown in Table 1.

| Parameter                        | Value  | Parameter                        | Value  |
|----------------------------------|--------|----------------------------------|--------|
| Weight (kg)                      | 3000   | Diameter of guide pulleys (mm)   | 310    |
| Material of tracks               | Rubber | Width of the guide pulleys (mm)  | 40     |
| Width of tracks (mm)             | 300    | Diameter of carrier rollers (mm) | 180    |
| Gauge of tracks (mm)             | 1350   | Width of carrier rollers (mm)    | 40     |
| Ground contacted length (mm)     | 1500   | Number of carrier rollers        | 2      |
| Track pitch (mm)                 | 109    | Diameter of tract rollers (mm)   | 160    |
| Diameter of pitch circle of driving wheels (mm) | 387 | Width of tract rollers (mm) | 150 |
| Number of teeth of driving wheels | 11     | Number of tract rollers          | 10     |
| Tooth width of driving wheel (mm) | 40     | Interval between tract rollers   | 380    |
| Diameter of guide pulley (mm)    | 350    |                                  |        |

3. Virtual prototype model

3.1. Establishment of virtual prototype model of the vehicle

In order to save the computing time, we should simplify the 3D model to suit the software computing. And the rule of simplification is that deleting the decorating part, ignoring the appearance and keeping the center of mass of the major part [6].

Then we use the same method to build other part of the vehicle in RecurDyn, include driving wheels, guide pulleys, tract rollers, carrier rollers, track adjuster and track frame. It is worth of noticing that
RecurDyn could not build the rubber tract directly, so we should utilize some equivalent method that we could create the common steel track and then change the material of the track shoes to the rubber [7]. After two steps mention above, we should merge two parts into one model. Then create the connections and springs based on the standard track structure. Finally, the whole virtual prototype model of the vehicle is shown in Figure 2.

![Virtual prototype model of the whole machine.](image)

**Figure 2.** Virtual prototype model of the whole machine.

### 3.2. Establishment of virtual prototype model of the ground
Based on the working conditions and working targets, we find that the hedge trimmer always drive on the relatively soft soil. Therefore, we establish the virtual prototype of the ground according to the Bakker theory [8] that recording the historical sinkage of the simulation, and the equation of the theory is as follow [9]. The detailed parameters are shown in Table 2.

\[
p = \left( \frac{k_c}{b} + k_j \right) z
\]

(P — Ground pressure;

\( k_c \) — Terrain Stiffness;

\( k_j \) — Soil friction deformation modulus;

\( b \) — Width of track shoes;

\( z \) — Sinkage;

| Parameters                  | Unit                     | Value          |
|-----------------------------|--------------------------|----------------|
| Terrain Stiffness           | \( k_c/N \cdot m^{(n+1)} \) | 0.35124        |
| Exponential Number          | \( n \)                  | 0.3            |
| Cohesion                    | \( \text{Pa} \)          | 1.379e-002     |
| Shearing Resistance Angle   | \( \circ \)              | 22             |
| Shearing Deformation Modulus| \( \text{K} \)           | 25             |
| Sinkage Ratio               |                          | 5.0e-002       |

### 4. Dynamic stability in typical working conditions

**4.1. Working on the straight ground**
It is the most usual environment for the hedge trimmer as is shown in Figure 3. Now, we know that the working velocity is 3km/h (angle velocity \( \omega = 4.29 \text{rad/s} \)); the friction to the track chassis, ignoring the air friction, is
\[ F_d = 0.17G = 5100N \]  
\[ (2) \]

\[ G \] — the vehicle’s weight

Therefore, the torque of each driving wheel is

\[ T = \frac{F_d}{2} \cdot r = 493N \cdot m \]  
\[ (3) \]

\[ r \] — the radius of driving wheels

STEP function is used as a driving function to set up the motion in the driving wheel, for reducing the initial oscillation at the beginning of the simulation [10]. The equation of the function is STEP \((TIME, 1, 0, 5, 4.29)\).

Because of the interval which is required to build the model between the vehicle and the ground at the beginning of the simulation, we set the first 1s of the simulation time as static equilibrium stage. The whole time and step of simulation is 15s and 500 respectively.

\[ \text{Figure 3. Working in the straight ground.} \]

\[ \text{Figure 4. The velocity of the center of mass in different direction.} \]

The Figure 4 shows that, when the speed of the vehicle is constant, the center of mass is fluctuating around the 830mm/s regularly, which is conformed to the designed velocity; the Figure 5 shows that, when the simulation begins, the hedge trimmer with high oscillating acceleration has a static balanced process, and then the acceleration of the center of mass in this curve is fluctuating, which shows that the machine is fluctuating slightly up and down in the vertical direction though, it could work well in this condition; Figure 6 shows that the average torque of driving wheel on one side is 480N.m and it is
fluctuating within a fixed reasonable range (2%) during the constant speed driving. In conclusion, the dynamic stability of the hedge trimmer working on the straight ground is reasonable.

![Figure 5. Acceleration of the center of mass in the vertical direction.](image1)

![Figure 6. Torque of the driving wheel.](image2)

![Figure 7. Working in the longitudinal gradient ground.](image3)

4.2. Working on the longitudinal slope
The hedge trimmer needs to be capable of climbing, as is shown in Figure 7. Now, we know the grade of the slope is 30° and the velocity is 2km/h (angle velocity ω=2.87rad/s).
The resistant force when climbing is 
\[ F = 0.65G \]  \hspace{1cm} (4)

The torque of driving wheel on one side is 
\[ T = \frac{F}{2} \cdot r = 1857.6N \cdot m \]  \hspace{1cm} (5)

The equation of motion is STEP (TIME, 1, 0, 5, 2.87); the time and step of the simulation is 30s and 1000 respectively.

**Figure 8.** The velocity of the center of mass.

**Figure 9.** Acceleration of the center of mass in the vertical direction.

Figure 8 shows that, the average speed is 0.54m/s (3% error compared with the theoretical value of 0.56m/s), and it is because that the type of the road, in the simulation, lead to the deeper sinkage of the track in the soil, which cause the greater friction between the internal parts of tracks; Figure 9 shows that the acceleration, in the process of entering the slope, is relative large, which indicates that it needs a period to be steady, and the acceleration in the vertical direction of the center of mass, in other time of the simulation, is fluctuating in a narrow reasonable range; Figure 10 shows that when the machine is working steadily on the slope, the average of torque of each driving wheels is 1800N.m with the 3% of
error compared with the theoretical value of 1857.6N.m. In conclusion, the dynamic stability of the hedge trimmer working on the longitudinal slope is reasonable.

![Figure 10. The torque of the driving wheel.](image1.png)

4.3. Working on the cross slope

When the hedge trimmer works on the cross slope, as is shown in Figure 11, it is prone to roll over and sideslip [11]. Therefore, we should testify its dynamic stability working on the cross slope. Now, we know that the typical grade of the cross slope is 30°, and other working parameters are the same as the vehicle working on the longitudinal slope. Because the maximum torque and velocity have been simulated in the Section 3.2, we only test its rolling angle in this part.

The equation of the function is STEP (TIME, 1, 0, 5, 4.29), and the time and step of the simulation is 10s and 500 respectively.

![Figure 11. Working in the crossing gradient ground.](image2.png)

Figure 12 shows that the rolling angle is almost unchanged and the same as the slope, which indicates that the hedge trimmer could not roll over in this working condition.
5. Conclusions
The author introduces an electric crawler type remote controlled hedge trimmer to reduce the emission and change the present status that hedges on the both sides of the highway are trimmed manually. And the author analysis its dynamic stability in three typical working conditions, which are straight ground, longitudinal slope and cross slope. And the research indicates that the electric crawler type remote controlled hedge trimmer has the reasonable design to perform a great dynamic stability.

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Figure 12. The rolling angle of the vehicle.