Design and research of meshing mechanism of orchard monorail transporter

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Abstract: The monorail transporter of mountains orchard had a compact size, strong carrying capacity, and can be installed in complex terrain, which can better meet the requirements of orchard use, and had received extensive attention at home and abroad. In order to improve the performance of the monorail transporter's meshing mechanism, this paper took the meshing mechanism as the research object, and designed the driving pin wheel with fixed pin teeth, the driving pin wheel with rotating pin teeth and a single-track model with four different tooth widths. The virtual prototype model of the meshing mechanism was built by ADAMS/View. The experimental data shows that the speed RMS value of the driving pin wheel with rotating pin teeth is increased by 135% compared with the driving pin wheel with fixed pin teeth during the meshing of the driving pin wheel and the single-track, and the contact force RMS value generated during the meshing process is reduced by 36%, and the tooth width of the single-track has less influence on the performance of the meshing mechanism. The experimental results show that the driving pin wheel of rotating pin teeth can significantly improve the performance of the meshing mechanism.

1. Introduction

The monorail transporter was a kind of rail-type transport equipment with the characteristics of high transport efficiency, strong carrying capacity, and low operating cost that had been gradually developed in the mechanization and automation production process of mountain orchards. Its use was conducive to liberating productivity, reducing labour costs, and improving the overall economic benefits of orchards [1].

The meshing mechanism of the monorail transporter was mainly composed of the driving pin wheel and the single-track, and the meshing mechanism had an important influence on the mechanics properties of the monorail transportation system [2]. In the driving process of the monorail transporter, the meshing of the driving pin wheel and the single-track actually expressed as meshing of the pin teeth and the single-track. At present, many scholars have carried out in-depth research on the influence of rail racks on the mechanics properties of transport systems in the meshing mechanism of monorail transporter, and have made extensive achievements [3]. However, due to the limitations of experimental conditions, the influence of the pin teeth of driving pin wheel and the tooth width of the single-track on the mechanics properties of monorail transporter was still lack of systematic research [4-6].
Based on this, the dynamic simulation analysis of the process of meshing the fixed pin teeth driving pin wheel and the rotating pin teeth driving pin wheel with the single-track by ADAMS/View software was carried out to study the influence of the movement state of the pin teeth on the mechanics properties of the monorail transporter. At the same time, combined with the virtual prototype technology to research the influence of the tooth width of the single-track on the performance of the monorail transporter when the rotating pin driving pin wheel meshes with the single-track.

2. The meshing mechanism and transmission principle of monorail transporter

The geometric model creation and assembly of the meshing mechanism of the monorail transporter was completed using the three-dimensional design software SolidWorks. The meshing mechanism mainly comprises a driving pin wheel, a single-track and a transmission shaft, wherein the driving pin wheel is composed of a driving wheel disc and eleven pin teeth, and the single-track is cut by a seamless 65 Mn spring steel pipe of 50 mm × 50 mm × 5 mm. The single-track is spot welded to the square steel track according to the pitch and meshing requirements, and the tooth width of the single-track is 10 mm. The working principle of the meshing mechanism is that the driving wheel disc on both sides of the driving wheel are connected with the transmission shaft through the hub, and eleven pin teeth structures are evenly distributed between the driving disc on both sides, among which the pin teeth are composed of a sleeve and a pin shaft. During the driving process, the driving disc on both sides of the driving wheel are subjected to the load mass, and the transmission is realized by the meshing between the pin teeth and the single-track. The parameters of the meshing mechanism of the monorail transporter are shown in Table 1.

3. Establish a dynamic model of the driving wheel and rack meshing mechanism

Import the 3D solid model of the driving pin wheel and monorail meshing mechanism assembled in SolidWorks into ADAMS/View in Parasolid format, set the unit system to MMKS and add the gravitational acceleration in the -Y direction to the gravity setting. In addition, the material properties of the driving pin wheel, driving shaft, pin teeth and single-tracks are set to 65 Mn in the material library. When establishing a virtual prototype model of the driving pin wheel and single-track meshing mechanism, it is necessary to add a collision force and a friction force between the driving pin wheel and the single-track, the pin teeth and the single-track.

In order to facilitate the research, in the process of dynamic analysis, each component is regarded as an ideal rigid body, and relevant constraints are imposed on the model according to the actual working condition of the driving wheel and the rack meshing transmission. A fixed joint is connected between the single-track and the ground, and a revolute joint is connected between the driving pin wheel and the driving shaft. When the pin teeth are fixed, a fixed joint is needed between the sleeve and the pin shaft and set the direction of movement of the driving wheel to the X-axis direction. The dynamic simulation and analysis of the meshing mechanism model were performed. The simulation time was set to 2 s, and the output of 2000 steps was defined. After the calculation is completed, enter the post-processing module of ADAMS to view the simulation results. The dynamic simulation models of the driving pin wheel meshing with the single-track are shown in Figure 1 to 2.
4. Simulation results analysis and verification

4.1. Speed-time curve analysis of the driving pin wheel and the single-track meshing
As can be seen from Figure 3 to 4, when the driving pin wheel of the fixed pin tooth and the driving pin wheel of the rotating pin tooth meshes with the rack, the rotational speed of the driving pin wheel in the X-axis direction gradually increased with time. According to the ADAMS post-processing data, the RMS value of the fixed pin teeth driving pin wheel speed in 0-2 s is 153.06 mm·s⁻¹, and the RMS value of the rotating pin teeth driving pin wheel speed is 360.32 mm·s⁻¹. During the meshing process between the driving pin wheel and the single-track, the speed of the driving pin wheel has a periodic law from large to small and then from small to large, because there is a polygon effect during the engagement of the driving pin wheel with the single-track. In the actual production process, the influence of the polygon effect during the meshing process can be reduced by increasing the number of pin teeth Z, reducing the pitch P of the rack and lowering the rotational speed of the driving wheel.

4.2. Contact force-time curve analysis of the driving pin wheel and the single-track meshing
As can be seen from Figure. 5 to 6, when the pin teeth of the driving wheel mesh with the single-track, the magnitude of the contact force exhibits an approximate periodic change with time, because the tooth stiffness changes periodically during the meshing, the contact force changes periodically with the change of the tooth stiffness. At the same time, there is large peak in the contact force curve, which was caused by the impact between the pin racks. The contact force spike corresponds to the peak of the output speed of the driving pin wheel. According to the ADAMS post-processing data, when the driving wheel of the fixed pin teeth meshes with the single-track, the RMS value contact force is 187.57 N, when the driving wheel of the rotating pin teeth meshes with the single-track, the RMS value of the contact force is 119.27 N.
In combination with Figure 5 and 6, in the process of the driving pin wheel meshing with the single-track, the running efficiency of the rotating pin teeth driving pin wheel is increased by about 135% compared with the fixed pin teeth driving wheel, and the rotating pin teeth driving pin wheel produced the RMS value of the contact force is approximately 36% lower than the driving wheel of the fixed pin teeth. In the case of ensuring the normal engagement between the driving pin wheel and the single-track, the smaller the contact force generate during the engagement, the less the wear of the pin teeth during the meshing process, which is advantageous for improving the service life of the pin teeth. Therefore, it is considered that the mechanics properties of the driving pin wheel of the rotating pin teeth when meshing with the rack is superior to that of the fixed pin teeth driving pin wheel.

5. Simulation analysis of the meshing of driving wheels with different tooth width racks

5.1. Influence of the Tooth Width of the Single-track on the Speed of the Driving Wheel

It can be seen from Figure 7 that the speed of the driving pin wheel in the X-axis direction is substantially the same when the driving pin wheel meshed with the four different tooth width single-track racks within 2 s. However, when the simulation time was close to 2 s, the speed of the driving pin wheel meshing with the different single-tracks of tooth width began to differ slightly. The velocity curve near 2 s is partially magnified and found that the velocity curves with tooth widths of 8 mm and 10 mm were almost coincident, while the velocity curves with tooth widths of 12 mm and 14 mm are almost coincident. The speed of the driving pin wheel when meshing with the 12 mm, 14 mm tooth width rack is slightly larger than that of the 8 mm, 10 mm tooth width single-track, but the overall difference was not obvious. From this, it can be concluded that the tooth width of the single-track has no significant influence on the speed of the driving wheel.

5.2. Influence of tooth width of single-track on contact force

It can be seen from Figure 8 that within 2 s, the contact force generated when the driving wheel meshes with the single-track of four different tooth widths are almost the same, with no obvious change. Under the condition that the contact force value $F$ is constant, the contact strain can be effectively reduced as the tooth width of the single-track increases. During the engagement of the pin teeth and the single-track, the reduction of the contact strain was beneficial to improve the service life
of the single-track, and as the tooth width of the single-track increases, the smoothness and safety of
the monorail transporter during operation are also increase. However, the tooth width of the single-
track is too wide, and the monorail transporter is prone to jam during the turning process.

Figure 8. Contact force-time curve of the driving pin wheel engaged with different tooth width single-
tracks

6. Conclusion
When the drive pin wheel meshes with the track, the speed in the X-axis direction increases with time.
Under the same load torque of the driving pin wheel, the driving efficiency of the rotating pin tooth
driving pin wheel is 135% higher than that of the fixed pin tooth driving pin wheel, and the contact
stress RMS value is 36% lower than that of the fixed pin driving wheel. During the operation of the
monorail transporter, the tooth width of the single-track has no significant influence on the speed of
the driving pin wheel and the contact force generate when the single-track is engaged. Increasing the
tooth width of the single-track can reduce the contact stress, thereby reducing the wear on the pin teeth
during the engagement of the driving pin wheel and the single-track. However, when the tooth width
of the single-track is too wide, the monorail transporter is prone to jam when turning.

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