Design of self-propelled asparagus mechanized harvesting device

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Abstract: At present, the harvesting process of asparagus still depends on manual work, which is faced with the problems of large labor intensity and labor shortage. At the same time, the growing law of asparagus is random and the growth height is different. This paper presents a mechanized harvesting machine of self-walking asparagus. The punching angle and cutting height of pneumatic punching mechanism and the inclination angle of feeding roller can be adjusted in a certain range, which can adapt to the wide working conditions and harvesting demands.

1. Introduction
Asparagus is a kind of high-grade and valuable vegetable, known as "one of the world's top ten famous dishes", which is regarded as a healthy food by European and American nutritionists and vegetarians. In recent years, the planting scale of Asparagus in China ranks first in the world⁴. However, the harvesting process of asparagus still depends on manual work, which is faced with the problems of high labor intensity and labor shortage. Accelerating the research and development of asparagus harvesting equipment is the necessary way to realize industrialization development of Asparagus⁵. There are two kinds of asparagus harvesting machinery: non selective and selective. When the non selective asparagus harvester works, it cuts and transports the asparagus together with the soil, and then separates the asparagus from the soil by vibration, and finally sorts the asparagus manually³⁻⁴. This paper presents a solution of self-propelled mechanized asparagus harvesting machinery. When the height of asparagus reaches the harvesting height, the controllable cutting tool parts quickly extend from the prepared position to the root of asparagus to complete the cutting action. After harvesting, the controllable cutting tool parts return to the present position.

General scheme of asparagus harvester
Asparagus is a perennial crop, which is generally suitable for sandy loam or loam with fertile soil, good aeration, deep soil layer, good drainage and water and fertilizer conservation. It should be planted in spring. As shown in Figure 1, the row spacing and plant spacing of green asparagus were 130-150 cm and 30 cm respectively. The best harvesting standard of green asparagus is 25-30 cm. When the temperature is high, it often exceeds 30cm due to untimely harvest.

The overall structure of asparagus harvesting equipment is shown in Figure 1. With the advance of asparagus harvester, asparagus enters into the inclined pinch roll. The air cylinder in the punching mechanism rapidly extends to drive the cutter at the front end to complete the cutting of asparagus. The cut asparagus is sent to the lifting conveyor through the pinch roll and finally falls into the collection box.
2. Functional structure

2.1. Punching shear mechanism
As the asparagus harvesting trolley moves forward, the asparagus enters the gap between the two pinch rollers, and then the air cylinder in front of the punching mechanism quickly extends to drive the cutter at the front end to cut the asparagus. With the continuous rotation of the two rollers, the asparagus is clamped and dropped on the conveyor. The tail end of the cylinder is connected with the connecting rod hinged on the sliding block, and the sliding up and down of the sliding block can achieve the adjustment of the cutting height of asparagus by the cutter. As shown in Figure 2, when the adjusting slider of the punching mechanism is at the lowest position and the highest position respectively, the included angle between the punching tool and the ground is 140 and 300 respectively. With the sliding of the adjustable rack in the vertical direction, the height difference between the punching tool and the ground is 213mm and 156mm respectively. The speed of punching cylinder is 0.25m/s, the stroke of punching is 0.1m, and the punching cycle of cylinder is about 0.8s.

2.2. pinch roll assembly
As shown in Figure 3, the asparagus cut by the pneumatic punching mechanism is transported to the lifting conveying component by the pinch roll and then falls into the collection box. The main part of the pinch roll assembly is composed of two sets of parallel power rolls and transmission gears. The angle of inclination between the axis of pinch roll and the ground can be adjusted between 29° and 54° to meet the cutting requirements of asparagus under different picking conditions. The power roll and driven roll of the lifting conveyor are installed on the adjustable frame, so that the conveyor belt can move synchronously when the adjustable frame is adjusted.

2.3. lifting and conveying components
With the adjustment of the angle between the pinch roll axis and the ground, the angle between the lifting conveyor belt and the ground can vary from 38° to 45°. In order to adapt to the change of the center distance of the conveyor belt, a belt tension mechanism is installed on the frame. The maximum height from the bottom of the lifting conveyor belt to the ground is 0.42m. In order to match the punching cycle of the air cylinder, the average speed of asparagus after punching on the lifting conveyor belt by the pinch roller in the vertical direction shall not be less than 0.6m/s.
3 Power configuration

3.1. Pneumatic punching components

The punching and cutting mechanism is provided with air source by air compressor. By referring to the manual modern practical pneumatic technology, the average air consumption of the cylinder and the power consumption of the air compressor are shown in formula (1) and formula (2) respectively. Among them, $q_{sa}$ the average air consumption of the cylinder (L/min), $D$ is the diameter of the cylinder (cm), $L$ is the stroke of the cylinder (cm), $d$ is the inner diameter of the pipe between the reversing valve and the cylinder (cm), $l_d$ is the length of the pipe (cm), $n$ is the working flatness of the cylinder (times/min), $p$ is the working pressure of the cylinder (Mpa). $k$ is the isentropic coefficient ($k = 1.4$), $p_1$ is the absolute pressure of the intake air (Mpa), $k_x$ is the correction coefficient, $p_c$ is the absolute pressure of the output air of the compressor (Mpa).

\[
q_{sa} = 0.0157(D^2L + d^2l_d)N(p + 0.102) \quad (1)
\]

\[
P = \frac{k}{k - 1} \frac{p_c}{6 \times 10^5 \left( \left( \frac{p_c}{p_1} \right)^{\frac{n}{k}} - 1 \right)} \quad (2)
\]

3.2. Pinch roll assembly

In the schematic diagram of pinch roll shown in Figure 4, the upward lifting speed of the cut asparagus is $v_{2y}$ (m/s), the tangential linear speed of pinch roll rotation is $v_2$ (m/s), the angle of inclination of pinch roll to the ground is $\alpha_2^2$, and $\omega_2$ is the angular speed of pinch roll rotation (rad/s). The calculation of rotational speed and driving power of pinch roll is shown in formula (3) and formula (4). The power $P_2$ (W) of drive pinch roll in formula (4) is composed of two parts, one is the power consumed to overcome the friction of pinch roll bearing, the other is the power consumed to lift asparagus to height $H_2$. $\mu$ is the friction coefficient of the bearing, $m_2$ is the total mass of the roller and the gear (kg), $Q_2$ is the efficiency of the asparagus clamping (kg/s), $d$ is the nominal diameter of the contact between the rolling bearing and the roller shaft (mm), $v_2$ is the tangential linear speed corresponding to the rotation of the pinch roller (m/s), $D_2$ is the diameter of the pinch roller (mm). Formula (5) is the torque required to drive the pinch roll (N.m).

\[
u_2 = \frac{2v_{2y}}{D_2 \cos \alpha_2} \quad (3)
\]

\[
P_2 = \mu m_2 g d_2 v_2 / 2 D_2 + Q_2 g H_2 \quad (4)
\]

\[
T_2 = \frac{P_2 D_2 \cos \alpha_2}{2 v_2} \quad (5)
\]

Figure 4. Working diagram of pinch roll

3.3. Lifting transport components

The $v_1$ of transmission speed of lifting conveying device is set to be the same as the linear speed $v_2$ of clamping roller, which is about 1.0 m/s. The calculation of the driving power and required torque of the lifting conveying assembly is shown in formulas (6) and (7). The power $p_1$(W) of the driving lifting conveying assembly in formula (6) consists of two parts, one to overcome the power consumed by driving lifting the bearing friction of the conveying assembly and the other to lift the power consumed by the asparagus to height $H_1$. The $\mu$ is the bearing friction coefficient, the $m_1$ is the total mass (kg) of the active and driven drive shaft with the belt, $Q_1$ is the efficiency of lifting and transporting asparagus (kg/s), $d_1$ is the nominal diameter (mm) of the contact between the rolling bearing and the drive shaft,
\( v_1 \) is the linear (m/s) of the belt, and \( D_1 \) is the diameter (mm) of the drive shaft in contact with the belt. Formula (7) is the torque (N.m) required to drive the drive shaft of the lifting conveying assembly.

\[ P_i = \mu m g d_1 v_1 / 2D_1 + QgH_i \]  
\[ T_i = \frac{P_i D_1}{2v_1} \]  

### 3.4. Travel drive

As shown in Figure (5), different from the traditional car body drive, which uses the engine to transmit power to the wheel through the transmission mechanism, in order to improve the trafficability of the self-propelled asparagus harvesting equipment and simplify the transmission mechanism, each wheel is equipped with a 200W (DC24V) brushless motor and a corresponding planetary gear reducer (the reduction ratio is 1:40). The forward, backward and steering of the car body are realized by the centralized control of the controller. When the driving car moves from the current position where asparagus has been cut to the next position where asparagus will be cut, it is assumed that the moving distance of the car body is 0.3m. If the punching cycle of the cylinder matches the moving speed of the walking car, the moving speed of the car shall be 0.375m/s.

![Figure 5. Propel drive motor configuration](image)

As shown in Figure 5, the car body movement is driven by four 24V DC brushless servo deceleration motors. In the RS232 serial communication interface, CANH and CANL are the high and low levels of the signal, GND is the signal ground, Rx is the RS232 signal receiving end, TX is the RS232 signal transmitting end. In the control interface, PUL + / PIL - is the positive and negative input of pulse, PUL +/PIL - is the direction control mode, and the motor between ERC+ and ERC - is in the enable state at low electric level. U1 / V1 / W1 is the power line of the motor. The motion state of servo motor is fed back in real time by encoder.

![Figure 6. Control wiring diagram of DC brushless servo motor](image)

### 4. Conclusion

The cutting tool at the front end of the pneumatic punching mechanism can adjust the punching angle by 14°-30°, and the height of the adjustable rack can adjust the height of 213-156mm asparagus from the ground.

The center distance of the conveyor belt in the lifting conveyor is configured according to the angle of the pinch roll axis and the ground is 29°, but when the angle of the pinch roll axis and the ground is adjusted between 29° and 54°, the center distance of the conveyor belt in the lifting conveyor will be changed, so the conveyor belt tension mechanism is equipped on the frame.

The driving mode of the walking driving device adopts the scheme that each wheel is equipped with DC servo motor and reducer, which simplifies the transmission structure and improves the trafficability of the equipment in the field operation environment.

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