Design of the full hydraulic driving high frame field operation vehicle

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Abstract: In China, field management mechanization of corn, tobacco and sugarcane with high stalks is an important technical problem in agricultural mechanization development. According to the characteristics of high stalk crops planted in different row spacing in the plain area of Henan province, this paper designed a full hydraulic driving field high frame operation vehicle, included power system, engine placement and M type three-wheeled high frame structure. It also adopted a closed hydraulic system fully driven by three hydraulic motors, hydraulic power steering system and hydraulic track adjustment system. Its maximum clearance height is 1,800 mm. Speed ranges from 0-17 km/h with the hydraulic control. The back wheel track adjustment ranges from 2,000-2,400 mm. It can solve the problems of the high cost price in complex transmission system of the most domestic off highroad vehicles that the track cannot be changed. In this paper, a field high frame operation vehicle for the high stalk crop in field management operation has been provided.

Keywords: high stalk crop, full hydraulic driving, three-wheeled, high traffic ability, field operation vehicle

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1 Introduction

Work vehicle technology of high stalk crops developed rapidly in the world. For example, Model JS-820 self-propelled sprayer and JS-120 tobacco topping machine by SAPPERI from Italy; Model Multitrike330, Multitrike355 and Multitrike370 fruit field management machine by DAMCON from Holland; and Model TRH65, AXH110 and TXH1400 nursery management vehicles by TECNOMA from France have all used the three-wheeled frame structure and hydraulic driving technologies. However in china, the field management operation in corn, tobacco and other high stalks crops are in lack of the corresponding supporting machinery technology. Especially in Henan province, corn, tobacco and other crops with high stalks have different growing row spacing or row spacing of the different crops in the same area are different. According to the machinery operation requirement of high stalk crop field management, when operation vehicle runs in rows it would not damage the crops. The full hydraulic driving vehicle technology of back wheel tread with adjustable three-wheeled can meet this requirement. Therefore, the high frame operation vehicle must satisfy the need that the back wheel tread can be adjusted with the row spacing changes and the vehicle has good traffic ability in the high stalk crops fields. At present, although we have developed self-propelled field operation vehicle, micro cultivator and hi-crop sprayer for high stalk crops in some individual area in China (Liu, J.J. 2008). These structures also have a series of problems such as simple structure, poor adaptability, less operation function and low safety reliability. The majority of the vehicle’s

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tread cannot be adjusted and applied to high stalk crops of different row spacing. Therefore, in view of the field management operation of corn, tobacco and other crops with high stalk crops, we need a model vehicle with convenient operation, good traffic ability and high operation field working efficiency.

2 Structure design

2.1 Design objective

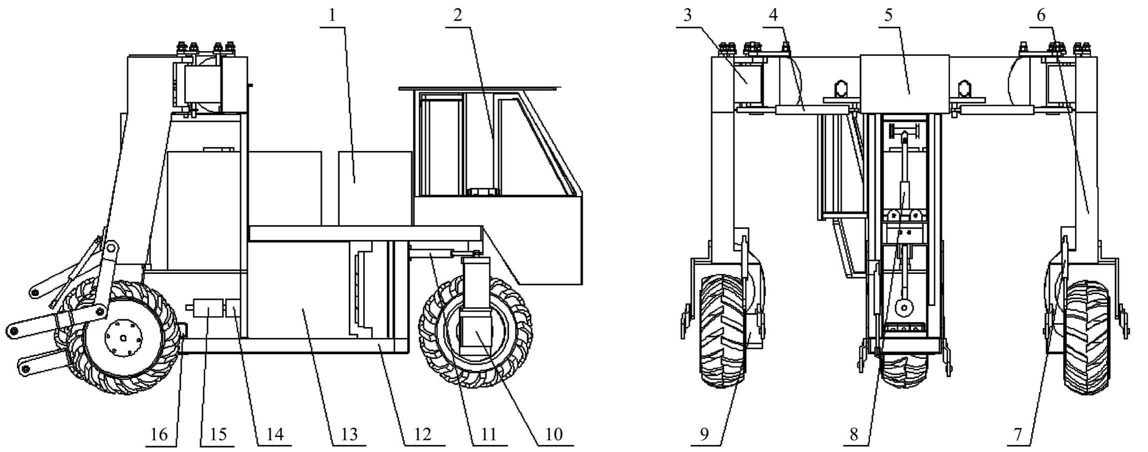
Through the investigation and study between domestic and foreign high stalk crop field machinery, to combine the characteristic of the high stalk crops planting in Henan local area, a full hydraulic driving high frame of field operation vehicle was designed for the plant spraying, tobacco topping, cultivation, drip irrigation pipe laying and other operational aspects in corn, tobacco and other high stalk crops. We designed the goals of the field operation vehicle as follows.

1) Three-wheeled M type high frame structure should make the vehicle pass through the high stalk crop rows smoothly, with a height less than or equal to 1,800 mm.

2) The back wheel tread can be adjusted. The back wheel tread in the road condition is 2,000 mm and that will increase to 2,400 mm in the field operation state. For example, in the distance of 600 mm in the corn field, the operation vehicle crossed 4 rows space. In the distance of 1,200 mm in the tobacco field, the operation vehicle crossed 2 rows space.

3) Adopting the hydraulic motor, output power and hydraulic hoisting device. It reduces the complexity of the chain, belt, gear and some mechanical transmission. It is convenient to connect with farm implements and hang tools; it improves the utilization rate of the implements and reduces the mechanical operation cost.

Full hydraulic driving high frame field operation vehicle mainly consists of three-wheeled M type high frame structure, intermediate power system, back wheel tread adjustment system and hydraulic system. Structure of the operation vehicle was shown in Figure 1.



1. Diesel oil tank 2. Cab 3. Back wheel tread adjustment mechanism 4. Tread adjustment hydraulic cylinder 5. Hydraulic oil tank 6. Frame 7. Implement lifting hydraulic cylinder 8. Lifting hydraulic cylinder 9. Back wheel hydraulic motor 10. Front wheel hydraulic motor 11. Steering hydraulic cylinder 12. Three-wheeled frame 13. Engine 14. Running hydraulic pump 15. Working hydraulic pump 16. Synchonous shunt motor.

Figure 1 Structure diagram of the operation vehicle

Three-wheeled M type high frame structure not only can improve the passing characteristics between the lines, but also can not damage the crops (Cheng, Y.S. 2004 claimed). The three wheeled vehicle’s turning radius was smaller than other one’s. Engine and power system placed in the middle position was convenient to connect the hydraulic pump and pipeline. The vehicle had a low position of the center of gravity, which was always in the middle position of the whole vehicle and the vehicle’s driving stability was better (Bodria, L.and M.Fiala, 1995; Spencer, H B. 1998 claimed). The vehicle adopted full hydraulic drive and the three hydraulic motors offered the torque around the same time, which ensured the vehicle’s dynamic performance. Steering system adopted full hydraulic steering with less noise and short lag time. The back wheel tread adjustment system changed the tread through the synchronization shunt motor to switch the field operation state and the road driving condition.

At the same time, the vehicle was also applied to the nursery field management operation through the tread adjustment, which realized the multifunctional use of the vehicle.

2.2 Technical parameters

The main technical parameters were shown in Table 1.

Table 1 Technical parameters of the operation vehicle

Parameters	Numerical value
Weight/kg	≤2600
Rated power/kW	40
Rated speed/r min^{-1}	2600
Back wheel tread/mm	2000-2400
Maximum height/mm	1800
Maximum width/mm	600
Minimum turning radius/mm	≤3.5
Range of speed/km h^{-1}	0～17
Clearance/mm	240
Front/back wheel diameter/mm	745

2.3 Safety analysis

The centroid position is an important parameter of the vehicle design. Different centroid location will affect the power, braking and safety. Therefore process of design should be strictly controlled.

Compared with the four wheeled vehicle, three-wheeled vehicle's stability was not all less than that (P.G., Van Valkenburgh et al. claimed). Jian, E.M. and T. Guo analyzed the dynamic rollover stability of agricultural three-wheeled transport vehicle and found out that centroid vertical position, height and turning radius had influence on the rollover stability (Jian, E.M. and T. Guo 1991). For the three-wheeled vehicle, back wheel tread is wider, centroid height is lower and the performance is better (Yang, J.S. et al., 2010).

Set the origin to the midpoint of the connection between the two wheels and the ground. Horizontally it was *X* axis to the right, the forward was *Y* axis and middle vertical was *Z* axis. Center of mass was *e*. The coordinate of *X* axis direction was *a*. The coordinate of the *Y* axis direction was *b*. The coordinate of *Z* axis direction was *h*. The centroid position of vehicle was calculated according to Equation (1), Equation (2) and Equation (3) (Zhang, C.B. et al., 2011).

$$a = \sum(G_i \cdot x_i) \Big/ \sum G_i \qquad (1)$$

$$b = \sum(G_i \cdot y_i) \Big/ \sum G_i \qquad (2)$$

$$h = \sum(G_i \cdot z_i) \Big/ \sum G_i \qquad (3)$$

where, G_i was quality of component *i*; x_i was value of *X* axis; y_i was value of *Y* axis; z_i was value *Z* axis.

After calculation, the centroid coordinates of the vehicle in the road condition was shown in Table 2 and the centroid coordinates of the vehicle in the field operation condition was shown in Table 3.

Table 2 Centroid coordinates of vehicle in the road condition

Item	In the road condition (back wheel tread was 2 m)		
	Normal driving (no implements)	Middle box with 300 kg chemicals	The back with 160 kg implements
a/mm	0	0	0
b/mm	1030	1020	990
h/mm	1030	1050	1040

Table 3 Centroid coordinates of vehicle in the field operation condition

Item	In the field operation condition(back wheel tread was 2.4 m)		
	Normal driving (no implements)	Middle box with 300 kg chemicals	The back with 160 kg implements
a/mm	0	0	0
b/mm	970	960	930
h/mm	1030	1050	1040

In Table 2, when the vehicle was in the road condition, *a*=0 m, *b*=1.03 m and *c*=1.03 m, the centroid position was located on the top level frame above the engine. When the middle box added 300 kg chemicals, centroid shifted rearward 0.01 m along the longitudinal direction and that shifted upward 0.02 m along the vertical direction. When the back of the vehicle hung 160 kg implements, centroid shifted rearward 0.04 m along the longitudinal direction and that shifted upward 0.01 m along the vertical direction.

Contrast to Table 2 with Table 3, as the back wheel tread of the vehicle became width in the field operation state, the origin position shifted forward 0.06 m along the longitudinal direction. In Table 3, when the vehicle was in the field operation state, *a*=0 m, *b*=0.97 m and *h*= 1.03 m, the centroid position was also located on the top level frame above the engine. When the middle box added 300 kg chemicals, centroid drifted was rearward 0.01 m along the longitudinal direction and that shifted upward 0.02 m along the vertical direction. When the back of the vehicle hung 160 kg implements, centroid shifted was rearward 0.04 m along the longitudinal direction and that shifted upward 0.01 m along the vertical direction.

Combining Table 2 with Table 3, Liquids added to the tank and implements hung to the back position will make a certain amount of offset of the centroid position. However, the center of mass was always located in the 2/3 wheelbase of the front of vehicle. At this time, the minimum load of the front wheel was 33.3% of the total weight and the maximum load of the rear wheel was 66.7% of the total weight. The operation vehicle was not easy to overturn, which can ensure the stability of running direction (Li, B. et al., 1993). From the viewpoint of safety, the lower the height of the centroid position became, the stronger the ability to resist overturning was. The centroid position could not be too close to the back of the operation vehicle. The vehicle requirements are as follows. The quality of the implements was less than or equal to 160 kg. The centroid position height was less than or equal to 1.1 m. The longitudinal distance between the back wheel and certroid was greater than or equal to 0.8 m (Figure 2).

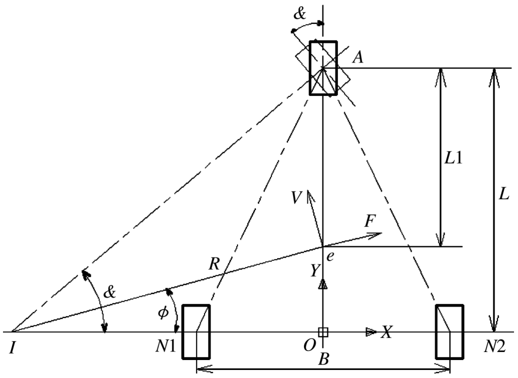


Figure 2 Steering model of the vehicle

Operation vehicle's minimum turning radius refers to the distance between the centroid and the point which is the intersection of front wheel steering plane's axis and back wheel's axis. Figure 2 is the vehicle's steering model, *e* is center of mass; *o* is the midpoint of the back wheel axis which is origin of coordinates. It builds xoy of the coordinate system. & is angle between front wheel steering plane and vehicle's longitudinal plane. *F* is steering centrifugal force, *V* is speed, *R* is the turning radius. The steering centrifugal force is as Equation (4).

$$F = \frac{W}{g}\frac{V^2}{R} \tag{4}$$

where, *V* is speed; *W* is gravity of the operation vehicle; *g* is acceleration of gravity.

Equation (5), Equation (6) and Equation (7) can be obtained. *R* is the minimum turning radius.

$$\sin \quad \phi = \frac{L - L1}{R} \tag{5}$$

$$\cos \quad \varphi = \frac{\sqrt{R^2 - (L - L1)^2}}{R} \tag{6}$$

$$\tan \quad \&= \frac{L}{\sqrt{R^2 - (L - L1)^2}} \tag{7}$$

Equation (8) can be obtained. The larger & was and the smaller the minimum turning radius was, the better the vehicle's steering performance was. After calculation, when & is 40°, the minimum turning radius is 3 m (Equation (9)).

$$R = \sqrt{L^2 \cot^2 \& + (L - L1)^2} \tag{8}$$

$$\frac{h}{B/2} = \frac{W}{F} \tag{9}$$

where, *h* is height between the centroid and the center point of the back wheel axis; *B* is the back wheel tread.

The Equation (4), Equation (8) and Equation (9) can be obtained. When the minimum turning radius was *R*, the steering speed of the operating vehicle was *V* (Equation (10)).

$$V = \sqrt{\frac{BgR}{2h}} \tag{10}$$

3 Hydraulic analysis

The planar four bar mechanism has the advantage of simple structure and strong bearing capacity, which can realize a variety of trajectories and laws of motion. It has been widely used in engineering practice (Guo, W.D., 2010; Yang, K.Z. et al., 2006). The operation vehicle realized the change of the tread in the running process with hinge four bar linkage mechanism. Figure 3 is the mechanism diagram of the back wheel. In the figure, *A*, *B*, *C* and *D* was the hinge center of rotation. Bar *AB* is cross beam. Bar *BC* is turning arm. Bar *CD* is back wheel support arm. Bar *CD* is pull rod. Bar *FE* is hydraulic cylinder. *O* point is symmetric center point of the beam.

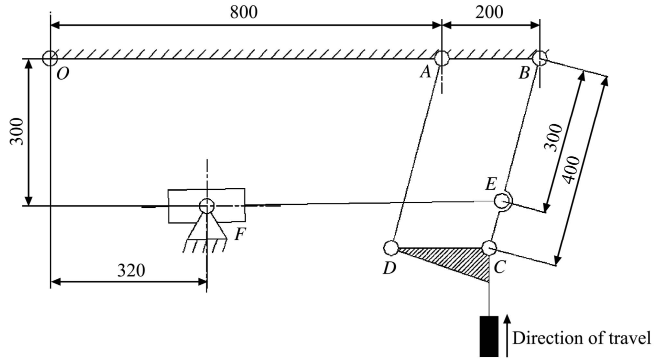


Figure 3 Mechanism diagram of the back wheel

In order to study the effect of the tread adjustment mechanism, the mechanical system dynamic software ADAMS (Ying, J.W. and Y.Z. Tao, 2004) was used to simulation and the three-dimensional model was built for tread adjustment mechanism with the Solidworks software. In order to facilitate the analysis, the blots and other fasteners (Zhang, Y. et al., 2009; Jia, J.X. et al., 2005 and Du, Y.F. et al. 2012) were omitted. The model would be imported into ADAMS through the data conversion and the material properties of each part should be defined based on Material Type command. Then, the tread adjustment of the vehicle would be simulated by applying kinematic pair and actual driving (Edelmann,·J. et al., 2011). Figure 4 is the trajectory diagram of the back tread adjustment. The track line was smooth with little change. This showed that the gesture of the rear wheel track adjustment was correct and achieved a smoothly change. Figure 5 is the curve of BAD angle. The rotation angle changed 40° in 2 s. The curve was approximately linear variation. The change of the angle was stable and did not have too much fluctuation. Figure 6 is the back wheel curve of displacement, velocity and acceleration. In the figure, the speed value increased stability and the curve fluctuations were relatively small. The back wheel speed direction was always positive and had the same direction with the vehicle's direction of travel. The acceleration curve was close to parabola with small curvature, which showed that the velocity changes were few. This reflected that the ground did not produce too much impact on the rear wheel. From the entire track line and curve, the back wheel tread changed stability and had little fluctuation.

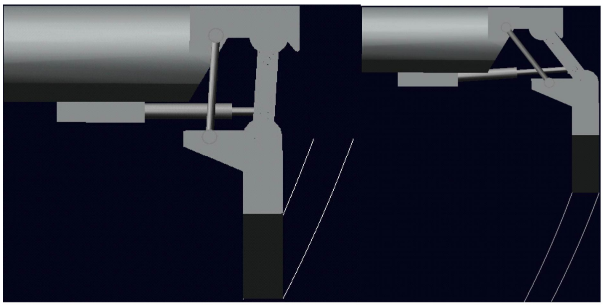


Figure 4 Trajectory of the back tread adjustment

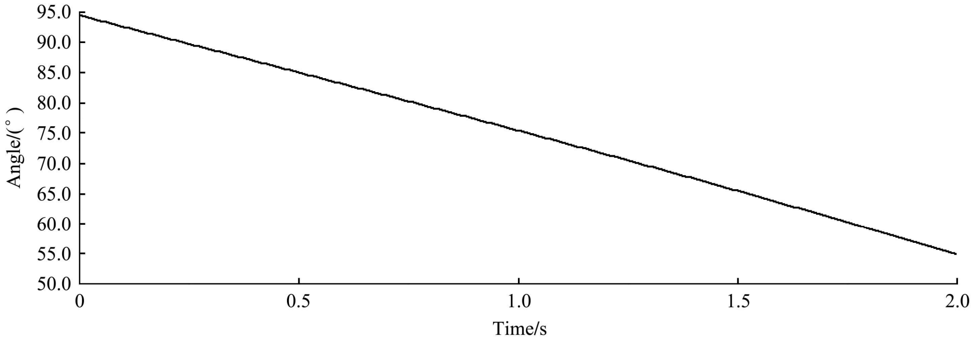


Figure 5 Angle curve

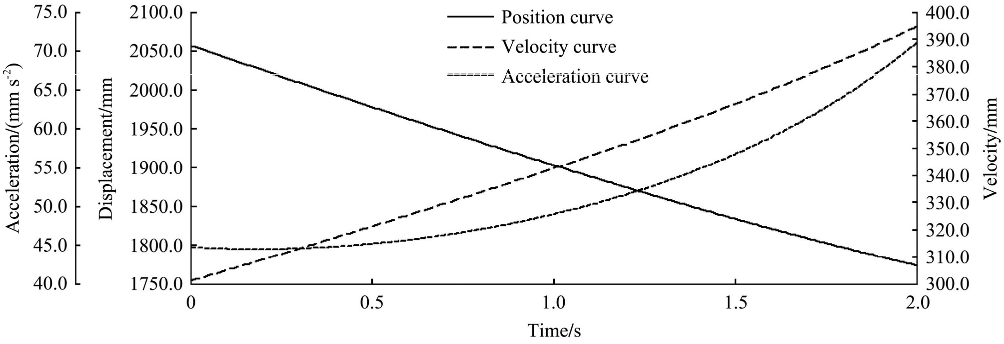


Figure 6 Displacement, velocity and acceleration curves

4 Conclusion

In the view of the main problems of affecting the vehicle's performance, design and research work had a series of calculations and simulation experiments. Then, three conclusions were drawn as follows.

1) Three-wheeled M type high frame structure ensured high trafficability of the vehicle in the high stalk crops. The maximum height was 1.8 m. The centroid height of the vehicle was less than or equal to 1.1 m. Relatively speaking, the position of each part was reasonable.

2) The centroid position and minimum turning radius were the large factors which affected the safety of the vehicles. The centroid position changed little wherever the vehicle was on the road or in the field after calculation. The minimum turning radius was 3 m; the rollover of the vehicle was relatively small.

3) The hydraulic adjustment simulation simulated the gesture of the back wheel tread adjustment. The theory was feasible that made the mechanism to bear a large torque for the vehicle in the fields. Design of the adjustment system should optimize in reducing of mechanism of the strength.

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