SIMULATION ANALYSIS ON THE PERFORMANCE OF SPLITTING AND PICKING DEVICES OF CORN HARVESTER
/
玉米收获机分禾与摘穗装置性能仿真分析

Tai Jianjian, Li Haitao *), Du Yuefeng, Mao Enrong, Guan Yunyi, Long Xinjiani [1]
[1)]China Agricultural University, College of Engineering, Beijing/China
Tel: +86-18612925066; E-mail: h89533@cau.edu.cn
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ABSTRACT

In the design of corn combine harvester, there is a high demand for customization and diversification in China. Aiming at the problems of backward design method, lack of design knowledge and long product development cycle, the discrete beam method is used to establish the corn plant model. The model of sub-device and the vertical and horizontal roller picking device is established by using UG, and the virtual prototype model is established by using ADAMS software. Meanwhile, the simulation experiments on the kinematics and dynamics performance of the separating device, the corn plant and the picking roller are carried out, and the simulation results are verified by field experiments. Through this method, the design parameters of the separating device and the picking roller are serialized, the method of evaluating the separating performance and the picking performance is provided, and the development and design cycle is shortened, which provides certain reference and theoretical basis for the development and design of the corn harvester header.

摘要

我国玉米联合收获机在设计过程中，存在定制化、多样化需求高的特点，针对其设计方法理论落后、设计知识匮乏，产品开发周期长等问题，采用离散梁法建立了玉米植株模型，利用 UG 建立了分装置器和纵卧辊式摘穗装置模型，运用 ADAMS 软件建立了其虚拟样机模型，进行了分禾装置与玉米植株以及摘穗辊运动学和动力学性能仿真试验，并通过田间试验验证了仿真结果的正确性。通过该方法实现了分禾装置和摘穗辊参数设计的系列化，提供了评价分禾性能和摘穗性能的方法，缩短了开发和设计周期，为玉米收获机割台的研发和设计提供了一定的参考和理论依据。

INTRODUCTION

Corn harvest is the most onerous link in corn production. The efficiency of artificial harvest is low and the labour volume is large, which requires a large number of labours (*Aguayo et al, 2017)*. The input of corn harvest labour volume accounts for 55% of the whole corn production link (*Zhang Xiru et al, 2019*). At the same time, corn harvest has the characteristics of short time, heavy task and agricultural time. Mechanized harvesting of corn has the advantages of improving corn production efficiency, reducing operation time, reducing corn production cost and realizing production and farmers' income increasing (*Cui Tao et al, 2019; Cook D. E. et al, 2014; Klopfensein et al, 2013*). China's mechanized corn harvest started late, due to the diversity of corn planting mode, the development speed of corn mechanization has been slow for quite a long time (*Du Yuefeng et al, 2014*). In 2017, China's mechanized corn harvest area reached 368 million mu, and the mechanized harvest level reached 69%, but it still lags behind the mechanized harvest level of wheat and rice (*Chen Zhi et al, 2014*). The low harvest level of corn mechanization is the main factor restricting the overall development level of corn mechanization in China (*Geng Aijun et al, 2016; Geng Duanyang et al*, *2017*).

In the process of mechanical product research and development, generally through prototype design, trial production, test and improvement, the development process has a long cycle and high cost, and many parameters are determined by the experience of the designer, which has a serious impact on the quality of the product (*Liu Hongxin et al, 2019; Alarcon R. Hunter et al, 2010*).

As a new technology in the field of design and manufacturing, virtual prototype technology can be used

[1]*Tai Jianjian,Ph.D.Eng.;Li Haitao, Prof. Ph.D. Eng.; Mao Enrong, Ph.D. Eng.; Guan Yunyi, Long Xinjiani*

to develop agricultural machinery products, which can significantly improve the above situation (*Ming Zhe, 2014; Herman C. et al, 2011*). In view of this, the three-dimensional model of the separating device and the vertical and horizontal roller picking device is constructed by three-dimensional software, and the motion simulation analysis is carried out by using ADAMS in order to provide theoretical basis and technical reference for further design of corn harvester.

MATERIALS AND METHODS

MODELING OF CORN PLANTS

When the header of corn harvester works, it is in direct contact with the corn plant, and there is mutual force between them (*Zhang Xirui et al, 2019*). Therefore, for the dynamic simulation of the main working parts of the corn harvester header, it is necessary to correctly model the corn plant and build an accurate virtual model of it, which plays a very important role in the process of simulation (*Gupta S. et al, 2017; Ranum P. et al, 2014*). Therefore, through the discrete beam method in ADAMS, the corn plant model is established; the corresponding binding force is defined, and finally the design and performance parameters of corn harvester are obtained.

In ADAMS, the method of discrete flexible connector is used to build the flexible body of corn plant. Firstly, two marker points are defined as the beginning and end of corn plant. The coordinates are Marker 1 (0,0,0) and Marker 2 (0,2200,0) respectively. Select [Build]→[Flexible Bodies]→[Discrete Flexible Link], and then the discrete flexible parts dialog box pops up, in which the parameters of corn plants can be set. After consulting the data, the Poisson ratio of straw is 0.33; the modulus is 1.1×10^{10} Pa; The density is 450 kg/m^3, and there are generally 10-20 knots on the corn plant. Taking Xianyu 508 corn plant as an example, according to the measured physical parameters of corn plant (*Du Yuefeng et al, 2012*), the height of corn plant is 2200 mm, the diameter of bottom end is 24mm and the diameter of ear point is 20 mm. During the simulation, 18 nodes are selected, and the diameter is gradually transiting, with the average height of 1050 mm. The established corn plant model is shown in Figure 1.

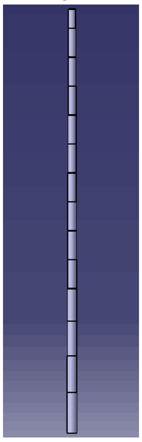


Fig. 1 - Discrete flexible connector model of corn plant

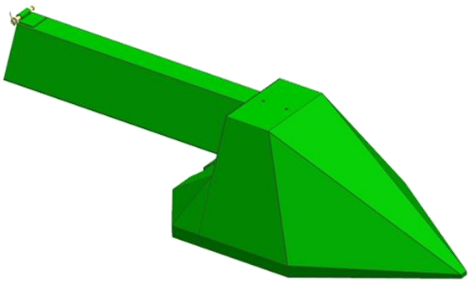


Fig. 2 - Three-dimensional model of the divider

SIMULATION ANALYSIS OF THE SPLITTING DEVICE

When the header of the corn harvester is working, the main function of the splitting device is to feed the corn plants into the clamping and conveying mechanism, so that the corn plants cannot be harvested (*Cui Tao et al, 2019*). Therefore, whether the design of the separating device is reasonable directly affects the working performance of the header of the corn harvester. The specific creation method is as follows:

(1) After consulting the relevant design methods and experience, the model of the splitting device is established in UG software, as shown in Figure 2. The model is imported into ADAMS in Para Solid format;

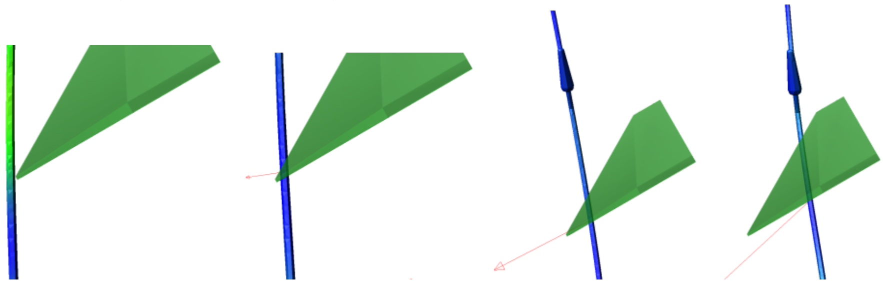
(2) Add a moving pair for the divider device;

(3) It is the initial forward speed of the harvester, and the initial speed in X direction is set as 2m/s;

(4) Add Solid To Solid collision type for the separating device and corn plants;

(5) Set the positive direction of X-axis as the forward direction of the harvester, the positive direction of Y-axis as the vertical downward direction of the ground, and the negative direction of Z-axis as the horizontal bending direction of corn straw when the separating device is working. The simulation plant starts to simulate

at the extreme position of the cutting edge of the splitting device, and the simulation process is shown in Figure 3. Figure 3.a shows the initial position of the corn plant and the splitting device, that is, the simulation starts at the extreme position of the cutting edge of the splitting device. Figure 3.b and 3.c show the position changes of corn plants and splitting devices in the progress of the harvester. Figure 3.d shows the moment when the splitting device is about to leave the corn plant, and the simulation is about to end. In the next process, the corn plant enters the picking device for picking.



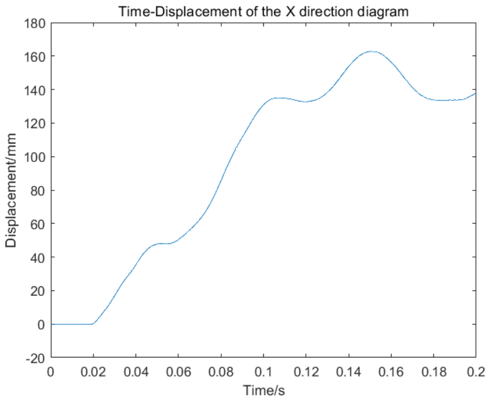
a b c d

Fig. 3 -The motion simulation process of splitting device

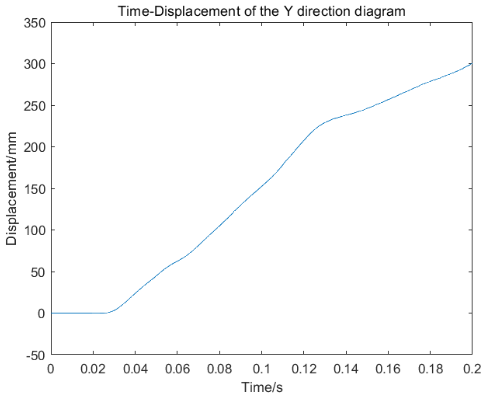
RESULTS

Action kinematical simulation of corn plant and its separating device

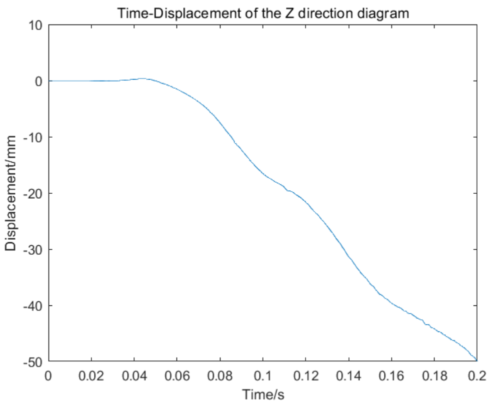
According to the actual situation, set the divider 500mm away from the ground, the simulation times is 0.2s and select 1050mm on the corn stalk as the average ear height. When the moving speed of the splitting device is 2m/s, the displacement simulation curve of corn plant ear point along the X-axis, Y-axis, Z-axis and synthesis direction under the action of the splitting device is shown in Figure 4.



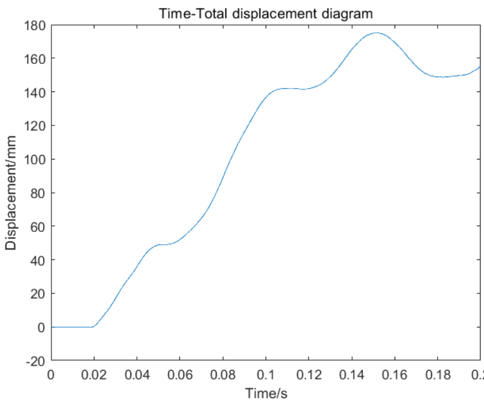
a. X-direction



b. Y-direction



c. Z-direction



d. Synthesis

Fig. 4 - Time-varying curve of displacement in different directions of corn plant ear point

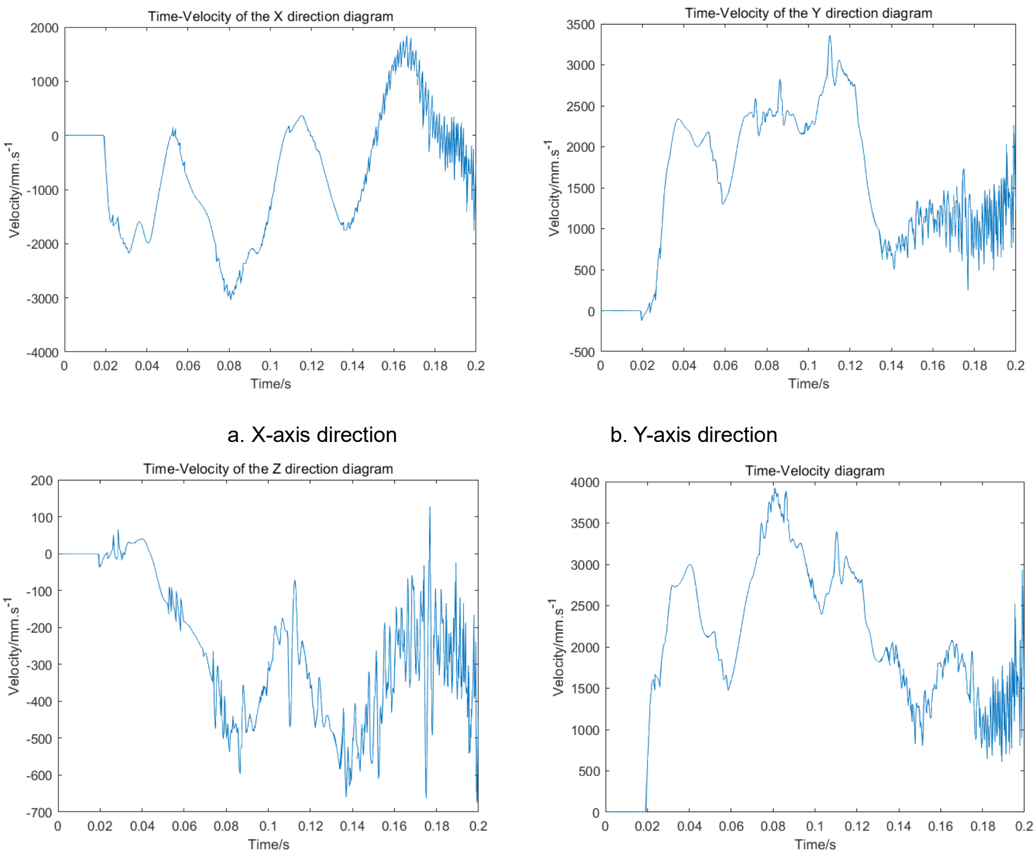
It can be seen from Figure 4.a that in the simulation process, in the X direction, i.e. in the direction of the harvester forward, the displacement at the ear point gradually increases, and the maximum displacement change is about 163mm, i.e. the bending amount at the ear point of the corn plant is 163mm. When the simulation reaches 0.15s, the displacement in X direction decreases suddenly.

This indicates that the corn plant is subject to large vibration and friction in the simulation process. It does not continue to move along the direction of the harvester, but in the opposite direction.

It can be seen from Figure 4.b that in the simulation process, the height from the ear point to the ground increases gradually in the direction of Y-axis, indicating that the height from the ear point to the ground decreases by 300 mm. When the simulation reaches 0.13s, the displacement suddenly increases, which shows that the corn straw is slightly vibrated in the simulation. It can be seen that there are some defects in the cone angle and shape design of the splitting device, which causes the corn plant to be pushed down when it is vibrated and affects the working performance of the splitting device.

Figure 4.c shows that in the simulation process, the displacement of the ear point of the corn plant increases gradually in the reverse direction of Z. Under the contact extrusion of the splitting device, there is a transverse bending in the negative direction of Z-axis, and the maximum displacement is 50 mm. Under the action of the splitting device, the corn device gradually moves inward without touching.

As shown in Figure 4.d, the maximum composite displacement is 178mm. The maximum bending angle between corn plant and the direction perpendicular to the ground is 10.4°in XY plane, and 25.4°in YZ plane. It can be concluded that the maximum angle between corn plant and vertical direction is 26.4°.



a. X-axis direction b. Y-axis direction

c. Z-axis direction d. Synthesis

Fig. 5 -Time-varying curve of speed in different directions of corn straw ear point

The simulation curve of ear point speed of corn plant under the action of the splitting device is shown in Figure 5. In the whole simulation process, the forward direction of X-axis at the ear point is 2 m/s and the reverse direction is 3.03 m/s. The results show that there is a great friction and vibration in the plant of the splitting device when the header move forward, which causes the corn plant to swing back and forth. The ear point moves along the positive direction of Y-axis, the maximum speed appears at 0.11s with 3.41 m/s in the whole simulation process; the average velocity on the vertical Y-axis is 1.42 m/s. Before 0.02s, the movement speed of ear point on the z-axis is relatively stable, and the speed increases gradually. The speed decreases gradually between 0.14-0.18s. In the whole simulation process, the average speed on Z-axis is 0.283 m/s, and the direction is negative along Z-axis. In the whole process of dynamic simulation, it can be concluded from the speed synthesis curve that from 0.02s to 0.2s, the speed reaches the maximum at 0.08 s, and then decreases gradually.

Dynamic simulation of the effect of corn plant and the splitting device

The main force of the splitting device is friction. When the speed of the device is 2m/s, the force simulation curve is shown in Figure 6.

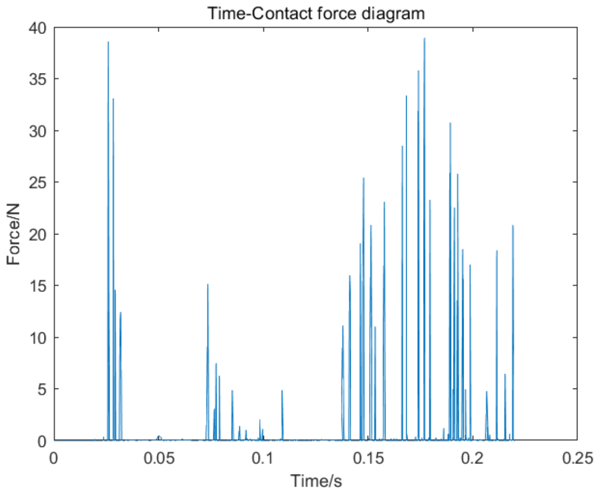


Fig. 6 - Contact force curve of corn plant and divider

Figure 6 shows the contact force curve between the corn plant and the splitting device. It can be concluded from the figure that at the beginning of the simulation, the contact force is large, reaching about 38N. When the simulation is at 0.25s, there are two big mutations in the contact force, indicating that the transition between the tip and the middle of the splitting device is not smooth, which hinders the movement of the corn plant. It is easy to break the plant at this time.

ANALYSIS AND SIMULATION OF THE PICKING DEVICE

Modeling of the picking device

The two rollers of the vertical and horizontal picking device are driven by gears, which are simplified when modeling, then imported into ADAMS software, and added some corresponding constraints, and then the dynamic simulation analysis can be carried out. When installing the stripping roller, the first is to ensure the accurate engagement position of the two gears, and the second is to consider that the retention time of the ear on the stripping roller is as short as possible, so as to reduce the loss of the ear (*Igathinathaneet et al, 2010*). Therefore, when installing, two picking rollers are not at the same height, and the inner picking roller is lower than the outer one. According to the design formula and experience, the model of the picking roller built in the 3D drawing software is shown in Figure 7.

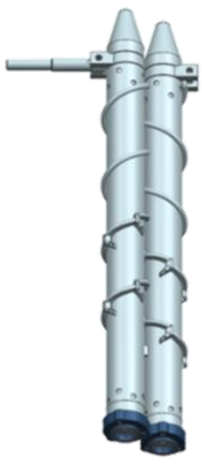


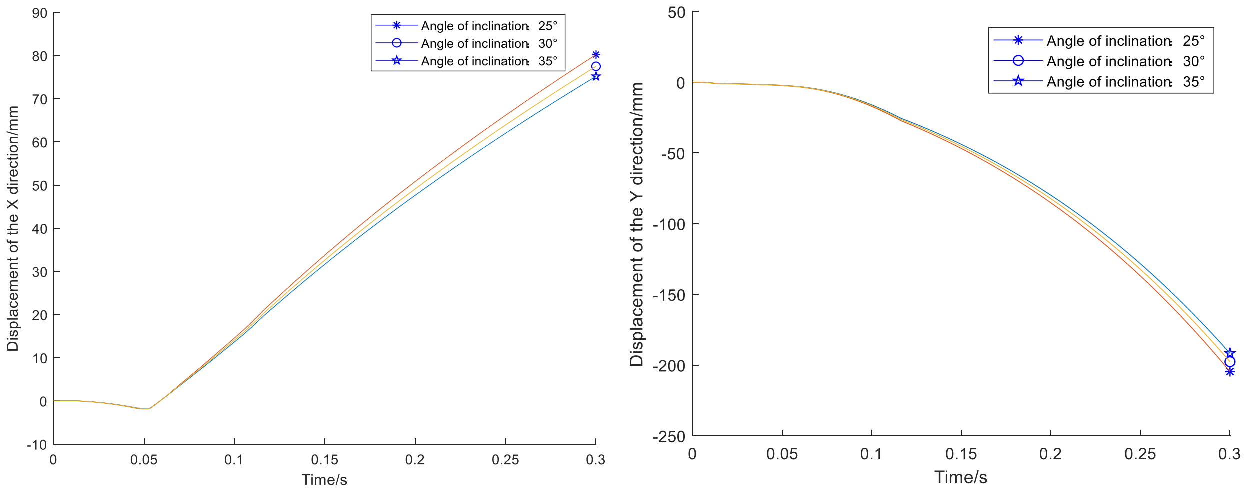
Fig. 7 - Vertical and horizontal roller model of the picking roller

The effect of the angle of picking roller on corn harvest

The horizontal picking device is mainly composed of a pair of relatively rotating picking rollers. The axis of picking roller is generally 25°- 35°to the horizontal, and the plants are fed along the axis of the picking roller. This paper mainly simulated the effect of the picking roller on the corn harvest performance when the axis and the horizontal plane of the picking roller are 25°, 30° and 35° respectively.

According to the actual situation, the average height of corn plant is 1050mm, the machine forward direction is X-axis, and the speed is 2 m/s. the positive direction of Y-axis is vertical and upward and Z-axis is transverse. Because the corn plant is clamped in the middle of the picking roller in the harvest, the displacement, speed and contact force of the ear point on the Z-axis are ignored. The speed of the picking roller is set to 1050r/min and the simulation time to 0.3s in order to simulate the working process of the picking roller.

Fig. 8 shows the time-varying curve of X and Y direction displacement at the ear point of corn plant under the action of picking roller when the angle between the picking roller and horizontal plane is 25°, 30° and 35° respectively.



a. X-direction b .Y-direction

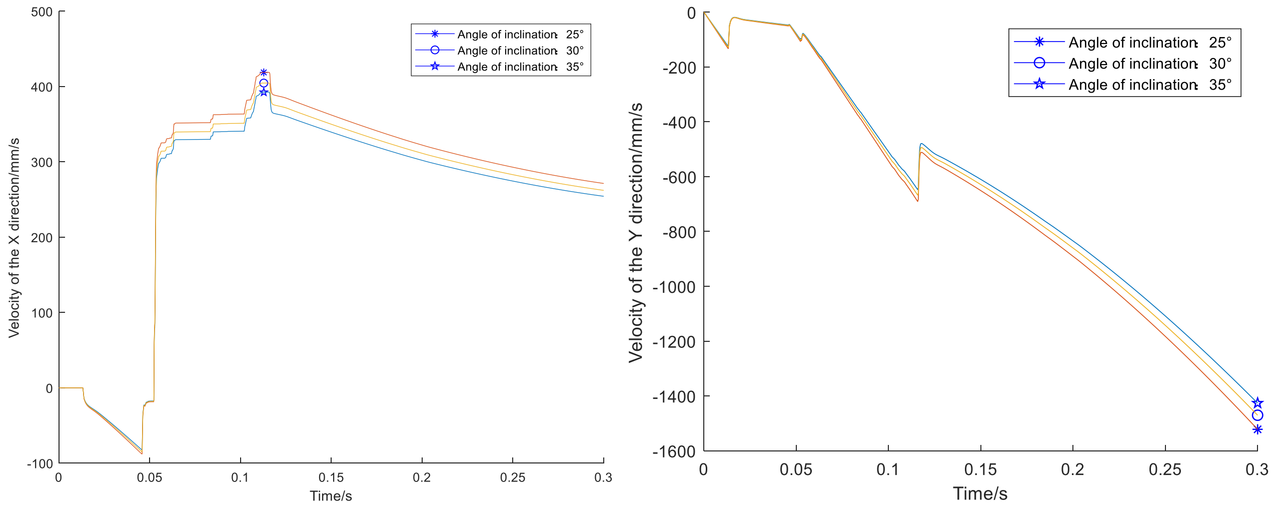
Fig. 8 - Time-varying curve of displacement in different directions of ear point under different inclinations of the picking roller

Fig. 8.a shows that the displacement of the corn plant heading point in the opposite direction of the machine is gradually increased over time, and with the increase of the inclination, the displacement is gradually reduced. It can be seen from Fig. 8.b that the displacement of the ear point of corn plant in the vertical downward direction increases gradually over time and the displacement decreases gradually with the increase of the inclination angle. Fig. 9 shows the time-varying curve of the speed in X and Y directions at the ear point of corn plant under the action of the picking roller when the angle between the picking roller and the horizontal plane is 25°, 30°and 35°respectively.

It can be seen from Figure 9.a that at the moment of contact and rotation with the picking roller and under the rotation of the picking roller, the corn plant tends to move towards the rear of the machine. Then, under the action of the forward speed of the machine, the corn plant gradually moves to the positive X-axis direction. With the increase of the inclination angle, the speed of the point where the ear is formed decreases gradually, and the fluctuation of the speed change decreases gradually in the process of picking.

It can be seen from Fig. 9.b that with the advance of the harvester, the vertical downward speed of the ear point increases gradually; with the increase of the inclination angle, the speed decreases gradually, and the fluctuation of speed change decreases gradually in the process of picking.

Compared with the simulation results, it can be seen that when the angle between the stripping roller device and the horizontal ground is 30°, its performance is more stable. Therefore, it is better for the new type of corn harvester to choose the picking roller with an angle of 30° to the horizontal ground.



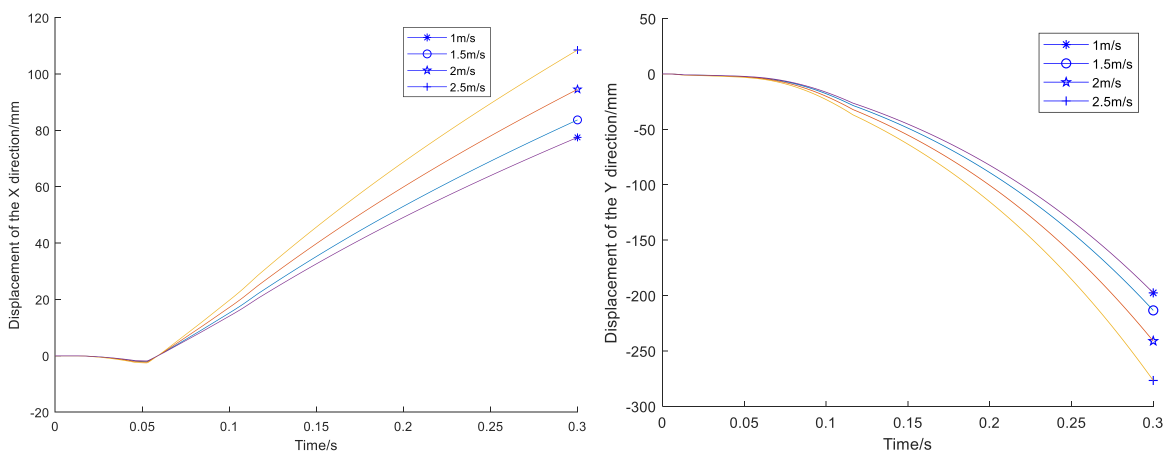
a .X-direction b. Y-direction

Fig. 9 - Time-varying curve of speed in different directions of ear point under different rake angles of the picking roller

The effect of the forward speed of the harvester on the corn harvest

According to the actual situation, the average ear setting height is 1050 mm on the corn plant, and the forward direction of X-axis is the forward direction of the harvester; the positive direction of Y-axis is the vertical upward direction, and the Z-axis is the horizontal direction. The displacement, velocity and contact force of ear setting point on the Z-axis are ignored because the corn plant is clamped in the middle of the picking roller in the process of harvest. The rotation speed of the picking roller is 1050r/min, the inclination angle between the picking roller and the horizontal ground is 30°, and the simulation time is 0.3s. In this paper, the forward speed of harvester is selected as 1 m/s, 1.5 m/s, 2 m/s and 2.5 m/s to simulate the working process of the picking device.

Figure 10 shows the displacement curves of X and Y directions at the ear point of corn plant under the action of different forward speeds. It can be seen from Figure 10a at different forward speeds, with the advance of the harvester, the displacement of the heading point in the forward direction of the harvester increases uniformly, and the displacement at the same time also increases with the increase of the speed. From Figure 10.b, it can be seen that at different forward speeds, with the advance of the harvester, the displacement of the heading point in the forward direction of the harvester increases uniformly, and the displacement in the same time also increases with the increase of the speed.



a. X direction b. Y direction

Fig. 10 - Time-varying curve of displacement in different directions of heading point under different forward speed conditions

Fig.11 shows the varying curve of contact force with time between the ear point of corn plant and the picking roller under different forward speeds. It can be seen from Fig.11 that with the increase of forward speed, the numerical fluctuation of contact force between the ear point and the picking roller also increases. This is because when the machine speed increases, its inertia in the forward direction is large, and the force on the straw increases.

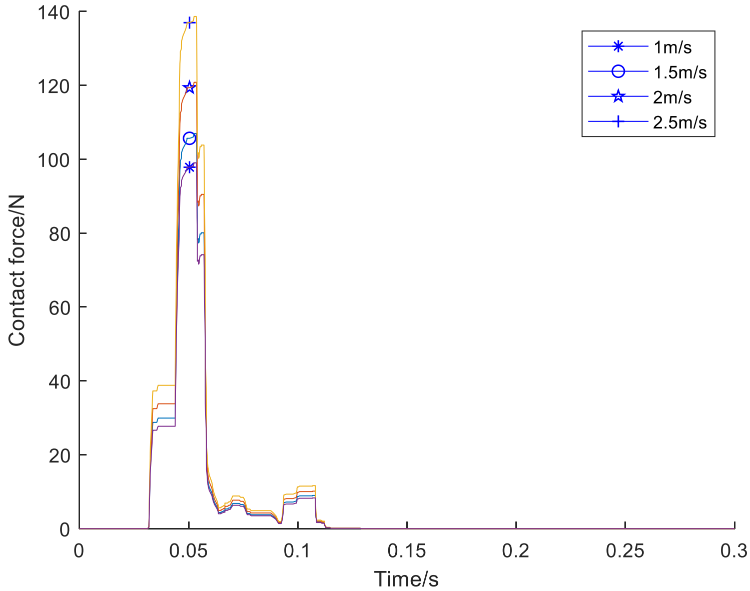


Fig. 11 - Time-varying curve of the contact force between the ear point and the picking roller under different forward speed

FIELD TRIAL

Test equipment and conditions

To verify the above simulation results, a field trial was conducted in Lingcheng District, Dezhou, Shandong Province, China in October 2019. In the test plot, the growth of corn plants was relatively uniform, and there was no lodging phenomenon and obvious drooping of ears. Zhengdan 958 was the corn in the experimental field. The moisture content of corn kernel and plant was 29.21% -33.64% and 76.63%-79.85% respectively. The planting row spacing was 580 mm, and the distance between adjacent horizontal roller picking mechanisms was 600 mm for harvest. The experimental equipment was a three row self-propelled horizontal roller ear harvester produced by China Wuzheng group. The test site is shown in Fig. 12.

Fig. 12 - Field test site

Test scheme and result analysis

Taking the damage rate and loss rate of the harvester as the evaluation index, the speed of picking roller is set at 800 r/min, and the harvesting quality is evaluated with different forward speed of the harvester and the inclination angle between the picking roller and ground. Through experiments and calculation statistics, the results are shown in Table 1.

Table 1

Effect of ear picking in field experiment

Forward speed of harvester [m/s]	Dip angle between the picking roller and ground [°]	Harvest damage rate [%]	Harvest loss rate [%]
1	25	0.31	0.04
	30	0.27	0.03
	35	0.32	0.05
1.5	25	0.43	0.05
	30	0.32	0.04
	35	0.44	0.07
2	25	0.56	0.07
	30	0.43	0.06
	35	0.58	0.07
2.5	25	0.59	0.08
	30	0.51	0.08
	35	0.62	0.09

According to Table 1, the damage rate of harvest varies between 0.31-0.61, and the harvest loss rate varies between 0.03%-0.09%. The results show that the loss rate and damage rate increase with the increase of the forward speed of harvester; with the decrease of the angle between the picking roller and ground, the damage rate and loss rate of picking both decrease and then increase. When the angle between the picking roller and ground is 30^{o}, the harvest damage and loss are the least and the harvest effect is the best. The correctness of the simulation theory is verified by field experiments.

CONCLUSIONS

1. Based on the mechanical characteristics of corn plant, the flexible body model of corn stalk is established by using the method of discrete flexible connector, and the key connection parameters and contact parameters of simulation are determined;

2. Through the establishment of the model of the splitting device, the kinematics and dynamics simulation of the corn stalk and the splitting device are carried out respectively. A method of evaluating the splitting performance is obtained, which takes the displacement of the corn stalk in different directions, the speed of the ending point and the contact force between the splitting device and the plant in the splitting process as the index;

3. Through the establishment of the model of the vertical and horizontal roller picking device, taking the displacement, speed and acceleration of the ear point in different directions as the evaluation indexes, the effects of the different angle of the ear plucking roller and the different forward speed of the harvester on the picking performance are mainly studied;

4. Through the three-dimensional model of the main parts of the corn harvester header, and the dynamic and kinematic simulation analysis, a series of motion parameters of the harvester header can be obtained, which can shorten the development cycle of the harvester, reduce the development cost, and provide reference and theoretical basis for its further optimization design.

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REFERENCES

[1] Aguayo M., Sarin M., Subhash C. et al, (2017), A corn-stover harvest scheduling problem arising in cellulosic ethanol production. *Biomass and Bioenergy*, Vol.107, pp. 102-112, England / Britain.

[2] Chen Zhi, (2014), Key technology and equipment of corn full value harvest. *China Social Sciences Press*, 2014. Beijing / China.
[3] Chen J.Y., Zhou Q., Xu G., Wang R.T., Tai E.G., Xie L., Huang X., (2019), Non-invasive blood glucose measurement of 95% certainty by pressure regulated Mid-IR. Talanta. England / Britain doi:10.1016/j.talanta.2019.01.034.
[4] Cheng Xianfu, Cong Yanyan, (2016), Rapid Design Method for Gantry Crane Based on Knowledge Reuse. *Machine Design & Research,* Issue 4, pp.145-148, Wuhan / China.
[5] Cook D.E, Shinners K.J., Weimer P.J. et al, (2014), High dry matter whole-plant corn as a biomass feedstock. *Biomass and Bioenergy*, Vol.64, pp.130-136, England / Britain.
[6] Cui Tao, Fan Chenlong, Zhang Dongxinget et al, (2019), Research Progress of Corn Mechanized Harvesting Technology. *Transactions of the Chinese Society for Agricultural Machinery*, Vol.50, Issue 12, pp.1-13, Beijing / China.
[7] Du Yuefeng, (2014), Design method and experimental research of self-propelled corn harvester in Hilly Area. *China Agricultural University*, Beijing / China.
[8] Du Yuefeng, Zhu Zhongxiang, Song Zhengheet et al, (2012), Simulation of Divider and Snapping Roll for Small-scale Corn Harvester. *Transactions of the Chinese Society for Agricultural Machinery,* Vol.43, Issue Z1, pp.100-105, Beijing / China.
[9] GengAijun, Yang Jianning, Zhang Ji. et al, (2016), Analysis of Influencing Factors of Corn Ear Harvesting Machinery Damage. *Transactions of the Chinese Society of Agricultural Engineering*, Vol.32, Issue22, pp.56-62, Taian / China.
[10] Geng Duanyang, Li Yuhuan, He Ke et al, (2017), Design and experiment of the gap clamping and conveying device for the header of vertical roller corn harvester, *Journal of Agricultural Machinery*, Vol.48, Issue 11, pp.130-136, Zibo / China.
[11] Gupta S., Garsa V., Kumar P., Malik V., (2017), Measurement of Anthropometric parameters of Ileum of 100 human hip bones in North Indian region. *Journal of the Anatomical Society of India*, 66, S115. doi:10.1016/j.jasi.2017.08.367.
[12] Herman C, Prochnow A, Heiermann M., (2011), Influence of chopping length on capacities, labour time requirement and costs in the harvest and ensiling chain of corn. *Biosystems Engineering,* Vol.110, Issue 3, pp.310-320, England / Britain.
[13] Hunter Alarcon R., Chueco J. Rios, Perez Garcia J.M. et al, Fixture knowledge model development and implementation based on a functional design approach. *Robotics and Computer-Integrated Manufacturing*, Vol.26, Issue1, pp.56-66, England / Britain.
[14] Igathinathane C., Womac A.R., Sokhansanj S., (2010), Corn stalk orientation effect on mechanical cutting. *Biosystems Engineering*, Vol.107, Issue 2, pp.97-106, England / Britain.
[15] Liu Hongxin T.J., Erickson G.E., Berger L.L. et al, (2013), Corn is a critically important source of food, feed, energy and forage in the USA. *Field Crops Research*, Vol.153, pp.5-11, Netherlands.
[16] Liu Hongxin, Zhou Xingyu, Jia Ru et al, (2019), Design and Reuse Technology of Mechanical Soybean Seed-metering Device Based on CBR. *Transactions of The Chinese Society of Agricultural Machinery*, Vol.50, Issue7, pp.39-50, Harbin / China.
[17] Ming Zhe, (2014), Simulation analysis of main components of corn harvester based on ADAMS. *Journal of Agricultural Mechanization Research*, Vol.36, Issue10, pp.33-37, Jilin / China.
[18] Ranum P., Pena-Rosas J.P., Garica-Casal M.N, (2014), Global corn production, utilization and consumption. *Ann NY AcadSci*, Vol.13 (12), pp: 105-112, New York / United States.
[19] Wang Jianting, Li Yaoming, Ma Zheng et al, (2019), Structural characteristics and development trends of key devices of corn harvesting machinery. *Agricultural Mechanization Research*, Vol.41, Issue 09, pp.1-8, Zhenjiang / China.
[20] Zhang Xirui, Wu Peng, Wang Kehenget et al, (2019), Design and experiment of 4YZT-2 type self-propelled fresh corn double ridges harvester. *Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE),* Vol.35, Issue13, pp.1-9, Qingdao / China.