

DESIGN AND APPLICATION OF A TEST BENCH FOR ROTATION TYPE ANTI-BLOCKING DEVICE OF NO-MINIMUM TILL SEEDER

少免耕播种机旋转类防堵装置性能试验台设计与应用

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ABSTRACT

Anti-blocking and seedbed cleaning are one of the key processes in no-minimum till seeding in the Northwest arid area in China. Soil tillage performance and straw cutting performance such as tillage depth stability, straw cutting ratio, torque requirement are important indexes that influence anti-blocking and seedbed cleaning performance. In order to investigate the performance of rotation type anti-blocking device of no-minimum till seeder under different operation parameters, this paper designed a rotation type anti-blocking device test bench. It mainly comprises frame, torque sensor, speed sensor, speed-adjustable motor, straw fixture, rotation blades and land wheel, its working width was 1100 mm. The torque requirement could be determined with torque sensor and rotation speed could be determined with proximity speed sensor. The test bench could hitch with test vehicle of soil bin to conduct experiment. With the test vehicle, travel speed could be adjusted; with the speed adjustable motor, rotation speed (0-300 r/min) could be adjusted; besides, operation performance of different rotation type device can be determined by changing the device. Soil bin experiment of idling test, tillage test and straw cutting performance test was conducted taking rotation speed as testing factors and torque and straw cutting performance as response indicators. Results showed that tillage depth stability of the test bench was 87.2%, and it could satisfy the test requirement and operation steadily. Results of the tillage experiment showed that torque requirement of tillage and idling test both increased with the increase rotation speed significantly; results of the straw cutting test preliminarily found that the critical cutting speed under supported cutting was between 100-200 r/min under the given condition. This study could provide reference for the performance research for anti-blocking device of no-minimum till seeder.

摘要

清秸防堵是中国西北旱区少免耕播种作业的重要环节之一。土壤耕作效果及秸秆切割效果如耕深稳定性、秸秆切断率、作业扭矩等是影响清秸防堵效果的重要指标。为了测定不同作业参数下少免耕播种机旋转类防堵装置的作业性能,本文设计了旋转类部件作业性能试验台,其主要由扭矩传感器、转速传感器、转速可调电机、秸秆夹持装置、旋转类刀具、地轮等部件组成,其工作幅宽为1100mm。作业扭矩通过扭矩传感器测定,实时转速通过接近转速传感器测定。其能够通过三点悬挂装置挂载在土槽台车上进行试验作业,通过调整台车前进速度,可实现不同前进速度下作业性能的测定;通过调整电机转速,可实现不同刀具转速作业性能(0-300r/min)的测定;此外通过更换装置还可实现不同结构装置对作业性能影响的测定。以刀轴转速为因素,以作业扭矩和秸秆切断情况为响应指标,应用试验台开展了空转试验、土壤耕作试验及秸秆切割性能试验。试验结果表明所设计试验台耕深稳定性为87.2%。工作稳定可靠,能满足试验需求。空转试验和土壤耕作试验均表明作业扭矩随刀轴转速的增加而增加,秸秆切断试验初步表明支撑条件下秸秆临界切断转速在100-200r/min之间。本文可为少免耕播种清秸防堵装置性能研究提供参考。

INTRODUCTION

Conservation agriculture (CA) has been widely adopted globally, showing great advantage to protect the soil from water and wind erosion, improve soil health and decrease input and make agricultural production systems sustainable (Ram et al., 2013; He et al., 2018; Friedrich et al., 2012.).

According to the research of *Cameron et al. (2014)* CA shows more potential in yield increasing in arid area for its capacity of saving water, such as northwest arid area in China.

The major principle of CA includes minimal mechanical soil disturbance by no-minimum till seeding; and maintenance of a permanent soil cover by mulch or growing cover crops (*FAO., 2012; Gao et al., 2003*). In order to ensure the anti-blocking and seedbed cleaning performance for no-minimum till seeding in Northwest arid area in China, straw cutting and seedbed tillage are often used as one of the key technical processes in the operation (*Gao et al., 2008; Zhao et al., 2020*). If the long straws are not successfully cut off, it would be likely to cause blockage by tangling in the opener or between two openers; if the seedbed was not tilled well, the seed cannot germinate successfully (*Vaitauskiene et al., 2017; Zhao et al., 2018*). Therefore, straw cutting and seedbed tillage performance of the relevant parts could directly affect seeding quality of till seeder.

However, it is usually difficult to obtain some straw cutting and seedbed tillage data in field operation, and it is not convenient to conduct comparison experiment on the straw cutting and tillage performance of different working and structure parameters of the rotation blades of no-minimum till seeder in field. To solve this problem, several straw cutting and tillage performance test benches have been developed. *Hou et al., (2014)*, designed a reciprocating cutting test bench for wheat straw, the cutting speed, forward speed, cutting angle and blade gap could be adjusted, the cutting force could be determined. Results showed that blade gap, cutting speed and cutting position had significant influence on the cutting performance. *Lu et al., (2014)*, designed a pendulum testing device to determine the critical kinetic energy and critical cutting speed of straw cutting, and found that straw diameter, moisture content has influence on critical kinetic energy and critical cutting speed. *Zeng et al., (2020)*, designed a tillage performance test bench which could adjust travel speed, torque, rotation speed of the shaft and tillage depth and collect torque and power consumption. *Li et al., (2012)*, designed a rotary tillage test device based on the soil bin test bench, which could collect resistance, torque and power consumption under different working parameters. These test benches could complete straw cutting or tillage experiment and obtain relevant data, but straw cutting torque under different working parameters cannot be tested, while it could generate significant difference in straw cutting performance. Besides, the tillage performance cannot be tested simultaneously.

To this end, this paper aims to design a test bench which could mimic straw cutting and soil tillage process. It could operate with the test vehicle of soil bin. The working parameters such as travel speed and rotation speed of the blade could be adjusted and the torque and rotary speed could be determined conveniently, the rotation type blade could be replaced as well, so as to determine the operation performance of rotation type anti-blocking device of till seeder.

MATERIALS AND METHODS

Structure of the test bench

Based on the requirements of straw cutting and soil tillage, the test bench which could mimic straw cutting and soil tillage process was designed. It mainly comprises the frame, torque sensor, speed sensor, speed-adjustable motor, land wheel, and rotation type blades, as shown in Fig. 1. The working width of the test bench was 1100 mm with two rows of rotation blades and the deepest tillage depth was 150 mm. Considering maize row space the distance between two blades was set as 600 mm. The disc blade could be replaced with rotary blade to test the performance of rotary tillage device.

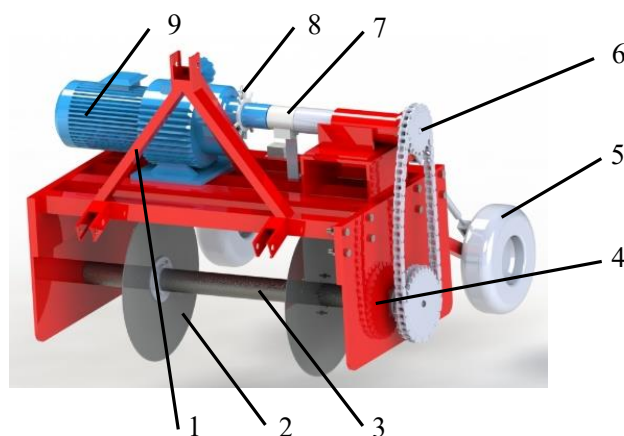


Fig. 1 - Test bench diagram

1. Three-point linkage; 2. Disc blade; 3. Cutter shaft; 4. Side board; 5. Land wheel; 6. Chain drive device

7. Torque sensor 8. Speed sensor 9. Speed-adjustable motor

Operation principle of the test bench

The straw cutting and soil tillage performance test was designed to be conducted as follows. Firstly, the rotation type anti-blocking device to be tested was installed on the shaft; then, the test bench was hitched on the testing vehicle of the soil bin. Secondly, the test bench was started by turning on the motor and the anti-blocking device began to rotate, then the rotation speed was adjusted to the testing value. Thirdly, a certain number of straw was clamped on the straw fixture. At last, the tillage depth was adjusted to the testing value and the testing vehicle of the soil bin could be started to pull the test bench travel forward to tillage or cut off straw samples. At the same time, the rotation speed and torque of the torque sensor was recorded. After one test, the test factors can be changed and the above process can be repeated to conduct the following experiment. The flow chart of the testing process is shown in Fig. 2.

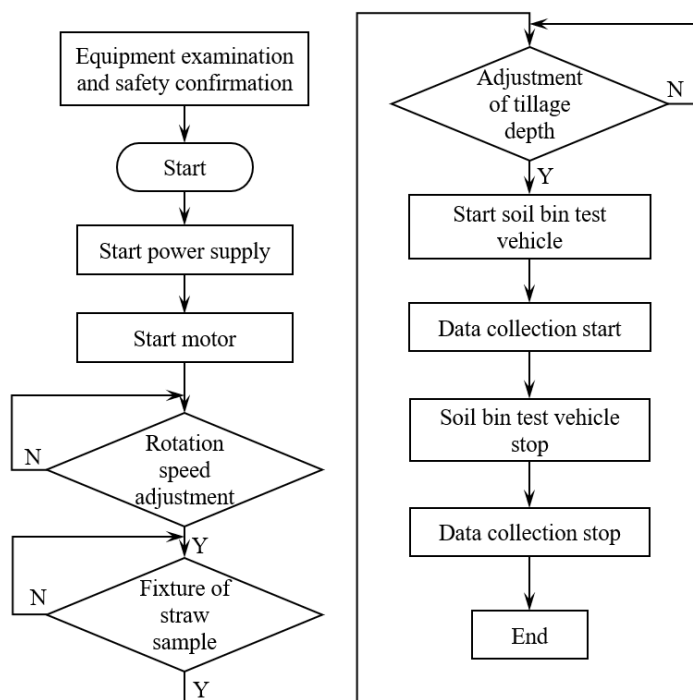


Fig. 2 - Flow chart of the experiment process

Rotation radius of the blade

The rotation radius of the blade is the summation of the shaft radius (38mm), the distance of shaft to soil surface and tillage depth. To avoid straw twining around the shaft, the rotation radius of the blade should not be too small, but with the increase of the rotation radius, arm of force would be longer and the torque requirement would be larger (Zhang *et al.*, 2009). Taking anti-blocking performance and design requirement of the test bench into consideration, the rotation radius of the blade was finally designed as $r=275$ mm.

Tillage depth

Based on the agronomy requirement in northwest arid area, the fertilizing depth of maize and wheat is about 8 cm, so that the tillage depth must be deeper than 8 cm. Apart from that, in the arid area, the moisture of surface soil is generally low and could not satisfy the requirement of seed germination. In order to ensure the quality of the seedbed and offer more moisture to the seeds, the tillage depth of rotation type device of no-minimum till seeder was generally deeper than 12 cm; this test bench was designed for experimental use, so the maximum tillage depth was designed as 15 cm. Tillage depth could be adjusted by adjusting the land wheel or the lifting height of the three-point linkage in the testing vehicle of the soil bin.

Rotation speed

Rotation speed of the anti-blocking device is one of the most important parameters that affect the performance of straw cutting and tillage. In the operation of the test bench, the motion of any point at the edge of the blade curve was the combination of uniform linear motion that travels with the test bench and circular

motion that circles with the shaft axis. The motion finally displays a trochoid motion in the vertical plane, as shown in Fig. 3.

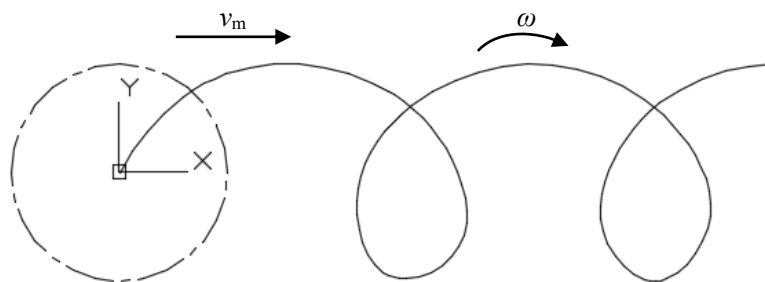


Fig. 3 - Trochoid path of any point at the edge of the blade curve

The kinematic equation of any point at the edge of the blade curve was

$$\begin{cases} x = v_m t + r \cos \omega t \\ y = r \sin \omega t \end{cases} \quad (1)$$

Where, v_m was the travel speed of the test bench; ω was angular velocity of the blade; r was the rotation radius of the blade.

Take the derivative of t , the absolute linear velocity of the blade tip was

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{v_m^2 + r^2 \omega^2 - 2v_m r \omega \sin \omega t} \quad (2)$$

And the linear velocity in x and y direction was

$$\begin{cases} v_x = v_m - r \omega \sin \omega t \\ v_y = r \omega \cos \omega t \end{cases} \quad (3)$$

Based on the research of *Ma et al. (2006)*, under the condition that the straw was laying on soil surface (e.g. one side support cutting), the straw cutting ratio was higher than 98% when the linear velocity of disc blade was larger than 7.4 m/s. According to the research of *Lu, (2014)*, under the manner of two side support cutting, the critical straw cutting speed was 2.86~3.46 m/s. In the operation of no-minimum till seeding, travel speed was about 1 m/s so as to avoid straw blockage caused by high travel speed. For experimental purpose, travel speed could be controlled and adjusted by the testing vehicle of soil bin ranging from 0-3 m/s. Take the above data into equation 2. Under one side support cutting manner, the rotation speed should be designed in the range of 222~291 r/min, under two side support cutting manner, the rotation speed should be designed in the range of 65~155 r/min, so the range of rotation speed should be available to be set higher than 291 r/min and lower than 65 r/min. The motor was selected with a speed adjustable motor, rotation speed could be adjusted mechanically from 0-3000 r/min. Chain transmission, which was frequently used in agricultural machinery was adopted in this test bench, the final transmission ratio was 19:30, while the drive sprocket has 19 teeth and the driven sprocket has 30 teeth. With this transmission system, the adjustment of rotation speed in the test range could be easily accomplished.

Straw fixture

According to the literature of agricultural mechanics written by *Geng et al., (2011)*, and the research conducted by *Zheng et al., (2016)*, supporting manners have vital influence on straw cutting performance and resistance. In order to test the straw cutting performance under different supporting manners, a pair of straw holding device was designed as shown in Fig. 4. It was composed of the top holding part and the bottom holding part, and a supporting pole was weld underneath each bottom holding part to stick into the soil and keep the straw cutting process stable. Before each experiment, the straw was fixed in different ways by the fixture to change the supporting manners of the straw cutting test.



Fig. 4 – Fixture of straw

Experiment description

Experiment was conducted in January 2022 in an indoor soil bin of College of Engineering and Electronics in Northwest A&F University. The soil bin was 60 m long and soil characteristics are shown in Table 1. The straw sample was collected on September after maize harvesting from experiment field of Northwest A&F University in Yangling, Shanxi Province, China. Its characteristics are shown in Table 2.

Table 1

Experiment condition of soil					
Soil texture	Soil moisture	Soil compactness/ kPa			
		5 cm	10 cm	15 cm	Mean value
Loam soil	15.32%	1135	994	1978	1369

Table 2

Experiment condition of maize straw		
Average straw diameter	Average straw moisture	Straw variety
15.4 cm	9.3 %	Shandan 650

During the experiment, the test bench was hitched on the back of the testing vehicle of the soil bin through three point linkage, so it could advance with the testing vehicle. The computer of the torque determination system was placed on the testing vehicle. Data was collected when the testing vehicle travelled with constant speed and the work of the test bench was stable.



a. Hitch on the testing vehicle of soil bin
 1. Testing vehicle 2. Designed test bench 3. Soil bin



b. Tillage test



c. Straw cutting test

Fig. 4 - Soil bin experiment

Tillage depth stability

In order to determine the operation performance of the test bench, tillage depth and tillage depth stability were determined after operation. Ten testing points were determined at each row and three rows were determined. Average tillage depth could be obtained easily. Tillage depth stability was calculated as follow:

$$\left\{ \begin{aligned}
 a_j &= \frac{\sum_{i=1}^{n_j} a_{ji}}{n_j} \\
 S_j &= \sqrt{\frac{\sum_{i=1}^{n_j} (a_{ji} - a_j)^2}{n_j - 1}} \\
 V_j &= \frac{S_j}{a_j} \times 100 \\
 U_j &= 100 - V_j
 \end{aligned} \right. \tag{4}$$

Where a_j was the mean value of tillage depth at route j , cm; a_{ji} was the tillage depth of point i at route j , cm; n_j was the determining number of route j ; S_j was the standard deviation of route j , cm; V_j was the variable coefficient of tillage depth at route j , %; U_j was the tillage depth stability of route j , %.

Determination of rotation speed

The rotation speed is one of the main factors affecting straw cutting performance, therefore it is important to collect rotation speed data during the experiment. The rotation speed was determined by a proximity speed sensor which could gather data when the distance of the sensor and metal material were closer than a certain value, which was 5 mm. The sensor was produced by Youyide Company in Dongguan, Guangdong Province. In order to improve the accuracy of the collected date, a notch disk was made with 10 teeth, so in each circle, the sensor could collect 10 signals, and the real rotary speed was calculated by the system and displayed on the screen.

Determination of torque requirement

FC-DAQ torque determining system was produced by Shanghai Forcechina Measurement Technology Company in Shanghai, China. The system consisted of a torque sensor, a storage battery and a computer. The torque sensor rotated with the shaft and its power was supplied by the storage battery, the torque data could be collected in real time and recorded by computer. Then the average torque was calculated and torque data could be used for analysis.

RESULTS

As observed during the tillage and straw cutting test, the test bench could rotate smoothly and operate well. Specific results of the tested index are described and discussed as follows.

Tillage depth stability

As shown in Table3, while target tillage depth was 10cm, the average value of actual tillage depth was 9.9, 10.0 ,10.1 cm in three experiment travels, respectively, and the depth stability was 88.4%, 86.8% and 86.5%, respectively, with an average value of 87.2%, which is higher than the requirement of National standard of 85% for rotary tiller. The results indicated that the test bench could operate steady and satisfy the experiment requirement.

Table 3

Tillage depth of three testing rows (cm)			
Testing point	Travel 1	Travel 2	Travel 3
1	9.7	10.1	10.2
2	10.0	9.9	10.3
3	10.0	10.0	10.0
4	9.9	10.0	9.9
5	9.8	9.8	10.0
6	9.9	10.1	10.3
7	10.0	9.9	10.1
8	9.9	10.2	10.2
9	10.1	9.8	10.2
10	10.0	10.0	10.2
Mean value	9.9	10.0	10.1
Stability	88.4%	86.8%	86.5%

Torque requirement of tillage test

Real time torque requirement of the tillage test and idling test of the test bench under three different rotation speeds is shown in Fig. 5. As we can see, the torque was relatively steady with a fluctuation in an acceptable range, which may be attributed to the texture of the soil and the vibration of the test bench equipment. Generally, the test bench could operate well.

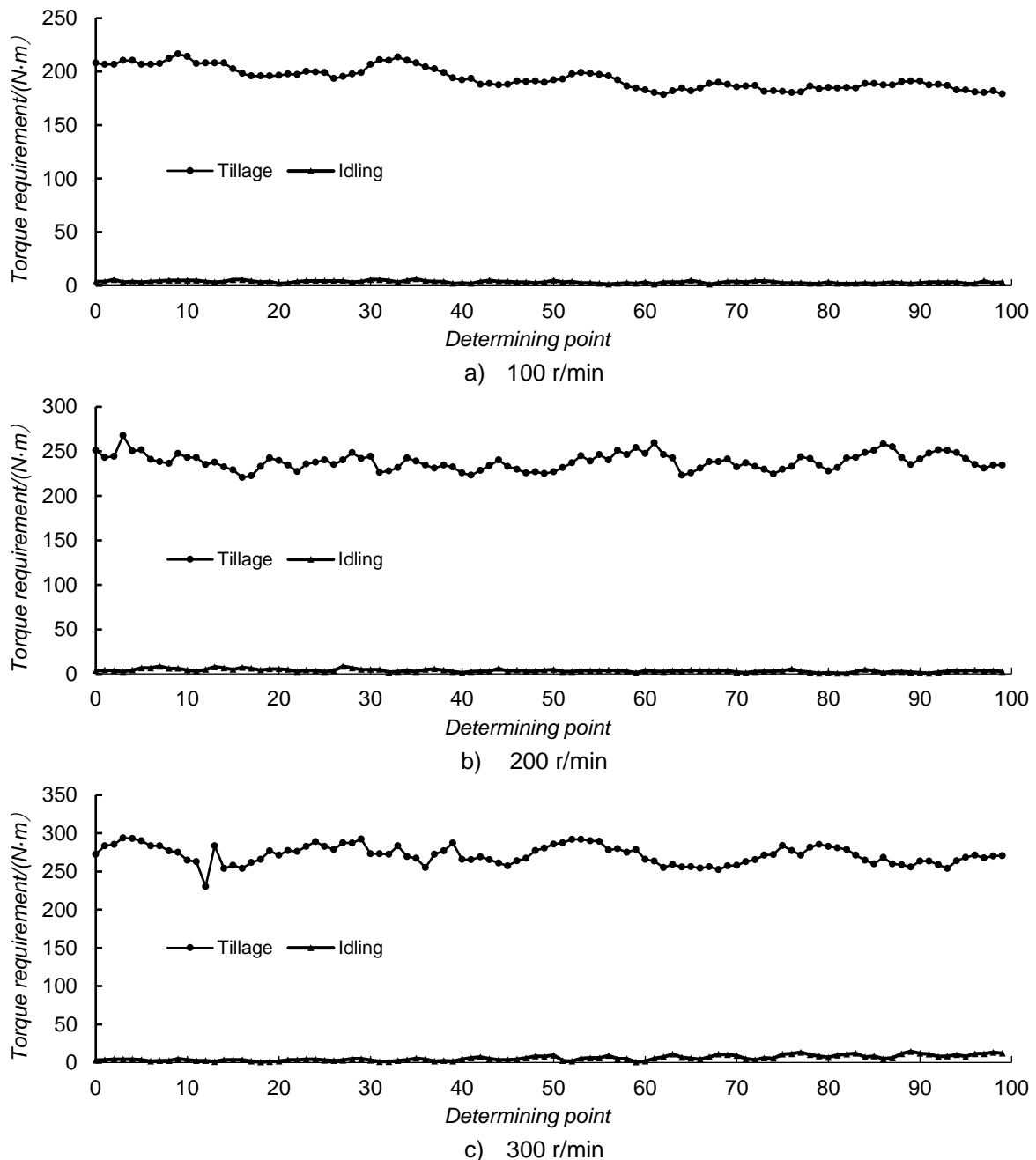


Fig. 5 - Torque requirement of the test bench

The average tillage torque requirement of the tillage test and idling test was calculated and the variance analysis was done, as shown in Fig. 6 and Table 4. The average torque requirement of tillage test was 193.7, 238.2 and 271.7 N·m under the rotation speed of 100, 200 and 300 r/min. The torque requirement increased significantly with the increase of rotation speed for tillage test. The same trend was also found in the average torque requirement of idling test, of which the torque requirement was 3.3, 3.7 and 3.9 N·m under the rotation speed of 100, 200 and 300 r/min. And the differences were highly significant. This phenomenon was also found by *Fang et al., (2016)*, and *Xiong et al., (2018)*, for the torque requirement of rotary tillage test, and the reason may be that, with the increase of rotation speed, the blade cut and threw more soil at certain period, so the friction and throwing resistance increased.

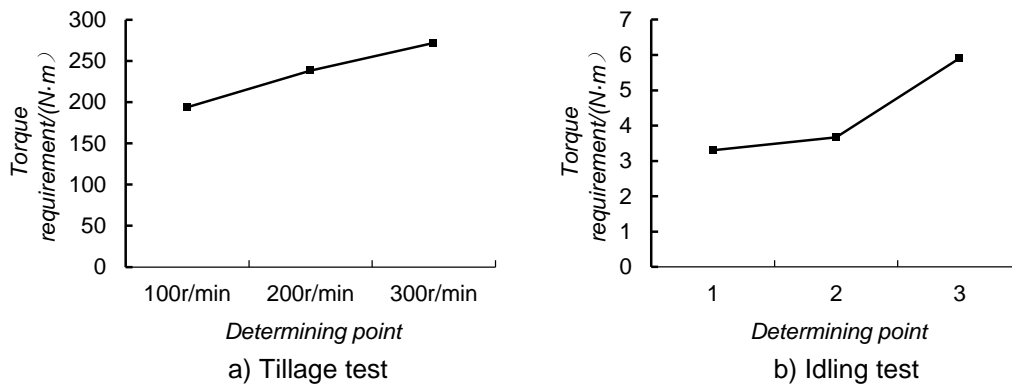


Fig. 6 – Average torque requirement of tillage test

Table 4

Variance analysis of the average torque requirement

	Source of variation	Sum of squares	Degree of freedom	Mean square	F	P-value	Significance
Tillage Test	interclass	309693.3	2	154846.6	1408.01	3.4×10^{-153}	**
	intraclass	32992.65	300	109.9755			
	Total	342685.9	302				
Idling test	interclass	399.9416788	2	199.9708394	36.80	5.1×10^{-15}	**
	intraclass	1630.520695	300	5.435068984			
	Total	2030.462374	302				

Note: ** indicates highly significant, $P < 0.01$; * indicates significant, $P < 0.05$.

Straw cutting test

With the increase of rotation speed of the blade, straw cutting performance changed. As shown in Fig. 7, the straw could not be cut off at the rotation speed of 50 r/min, and when the speed increased to 100 r/min, the straw sample was ruptured (Fig. 7 a). And when the rotary speed increased as high as 200 r/min, the straw was cut off, as shown in Fig. 7 b. The results indicated that the critical speed when the straw was cut off was between 100-200 r/min for the collected straw samples under supported cutting manners, which was in accordance with the results of study by *Ma et al., (2006)*, and *Lu, (2014)*. These results indicate that the test bench was reasonably designed, and the specific critical speed should be investigated further.



a. 100 r/min



b. 200 r/min

Fig.7 - Results of straw cutting test

CONCLUSIONS

(1) A straw cutting and seedbed tillage performance test bench for rotation type anti-blocking device of no-minimum till seeder was developed. It mainly comprises the frame, torque sensor, speed sensor, speed-adjustable motor, land wheel, and rotation type blades. With this test bench, travel speed, tillage depth, rotation speed of the blade and supporting manner of the straw could be adjusted, torque and rotation speed of the test bench could be collected.

(2) Key structural parameters and working parameters of the test bench were designed. The rotation radius of the blade was 275 mm, the rotation speed was designed to change between 0-300 r/min via the speed-adjustable motor and the transmission ratio was 19:30.

(3) The soil tillage and straw cutting performance test was conducted successfully. The torque was steady and fluctuated in a limited range, and tillage depth stability was 87.2%, higher than the national standard of China. It indicates that the test bench could operate well.

(4) Results of the tillage experiment showed that torque requirement of tillage and idling test both increased with the increase of rotation speed significantly; results of the straw cutting test preliminarily found that the critical cutting speed under supported cutting was between 100-200 r/min under the given condition.

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