Computer Simulation Design and Test of Self-Driven Stubble-Breaking Combined Cultivating Machine

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***Abstract* - Stubble-breaking cultivating machines suffer from problems such as consuming large amounts of energy while working. In this paper we propose to use simulation to design and test a self-driven stubble-breaking combined cultivating machine that can work with large-power tractors and meet the conservation tillage agriculture technical requirements. The key parts are designed, such as the transmission system, cutting stubble device and self-driven wheel using computer simulation and includes calculating the size and analyzing the track of the moving parts. The range of self-driving wheel's revolving speed is 53 - 80 r/min. Field test results show that compared with traditional rotary tillers, the cutting stubbles rate has reduced to 5.4%, mashing clods rate has declined to 16.7%, and fuel consumption has saved 16.7%, which met the requirements of corn no-till seeding of ridge culture area in northeast China. The work provides references for further study on large high efficiency and energy saving implements.**

Keywords - stubble-breaking cultivating machine; self-driven, design; test; computer simulation

I. INTRODUCTION

With conservation tillage technology getting more and more mature, the advantages in sustainable development are gradually recognized by people compared with traditional ways of farming for the environment, the applied range of conservation tillage has also been gradually expanded in China.

In order to adapt to the new models of farmland homework, large-power tractors were introduced and equipped in Heilongjiang reclamation area, but there was short of domestic combined cultivating machines, so it mainly relies on imports currently [1].Stubble cleaning project has high strength and working resistance that needs a tractor to provide a lot of power to keep normal work and causes a huge energy consumption. The study of stubble-breaking combined cultivating machine in China mainly focused on the design of subsoiling components[2] and smashing clods components[3][4] and the optimize of stubble breaker's structure parameters and dimension parameters[5][6][7][8], the progress has been made in improving cutting stubbles rate but the researches about saving energy are relatively less.

Aiming at the above problems, the new self-driven stubble-breaking combined cultivating machine was designed that can work with large-power tractors and its converts the torque originated from the friction between self-driven wheels and grounds into the rotary driving force of stubble cutter shaft, which reduces the energy consumption of work effectively on the basis of keeping the cutting stubbles rate and smashing clods rate, achieves the goals that give full play to efficiency of large-power tractors, saving cost and improving efficiency.

II. TECHNICAL DESIGN OF WHOLE STRUCTURE AND ITS WORKING PRINCIPLES

A. Technical Requirements

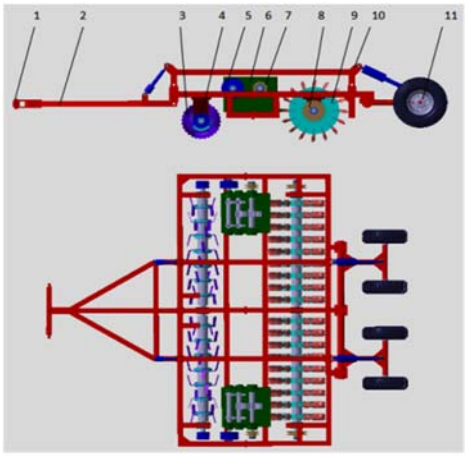
According to the working condition of the machine and agronomic requirements were as the followings.

(1)The working performance meets the requirements of corn no-till seeding of ridge culture area in northeast China and cut stubble effectively[9][10].

(2)There are good mobility, small vibration and stable performance.

B. Structure and Working Principles

The whole structure is shown in Fig.1 which is composed with traction beam, triangular support, frame, road wheels, stubble-breaking device, belt drive unit, gearboxes, chain transmission device, self-driven wheels, etc. Stubble-breaking device, drive system and self-driven wheels are the main research content in this paper.



1 traction beam;2 triangular support;3 stubble-breaking device;4 small belt wheel;5 big belt wheel;6 gearbox;7 small chain wheel;8 big chain wheel;9 self-driving wheel;10 frame;11 road wheel

Figure. 1 Instruction Diagram of Stubble-Breaking Combined Cultivating Machine

The stubble-breaking combined cultivating machine is dragged by the tractor drags with hydraulic hitch system, the torque that comes from the friction between self-driven wheels and grounds propel the self-driven shaft to work, the stubble-breaking device cut stubble and mash clods by the impetus delivered from chain drive device, gearboxes and belt drive device, grip hooks on the self-driven wheel embed into the grounds can also accomplish a certain degree of cutting stubble and smashing clods operations, the working depth is adjusted by limit-deep cylinder. The impetus is not provided by tractor but transformed from the torque, which achieves the goals that reduce the tractors output. The machine not only can install the stubble-breaking device but also install soil preparation equipment, deep scarification device even fertilization and seeding device, it has certain extensibility and extensive applicability. The main technical parameters are shown in Tab.1.

TABLE 1. MAIN TECHNICAL PARAMETERS

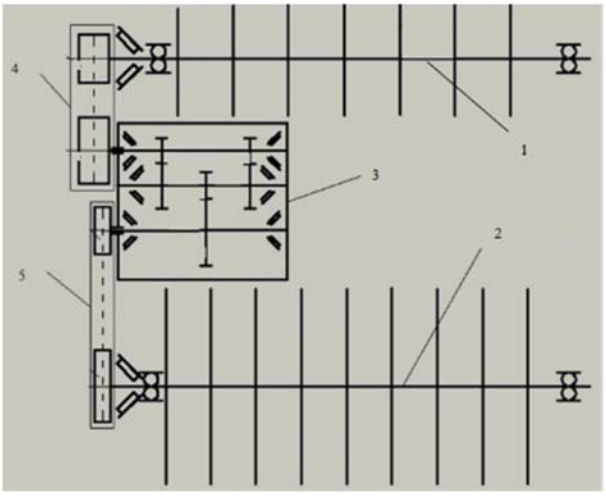
Items	Parameters	Items	Parameters
Dimensions(length, width ,height)/mm	8000×5570×1300	Stubble cutter shaft's diameter/mm	500
Working width/mm	4200	Stubble cutter shaft's revolving speed/rad·Min-1	904～1365
working speed/km·h-1	8～12	Stubble-breaking depth/mm	720
Self-driven wheel's diameter/mm	1075	Tractive power/Kw	180～220

III. DESIGN OF THE KEY PART

A. Drive system

The machine's impetus comes from self-driven wheel, but its revolving speed is limited by the machine's forward speed, hence cannot provide higher speed for stubble cutter shaft. In order to meet the requirements of the straw returning technology and the rated revolving speed of stubble cutter shaft, the speed variation is installed in drive system.

Design requirement of drive system is that all aspects of operations are reasonable, which not only meet the requirements of revolving speed but also ensure the size of the machine that is minimal, the design scheme are shown in the Fig.2. The structural pattern is double-shaft, and the self-driven wheels are rotated rely on the friction. The revolving speed increased with chain drive, secondary gearboxes and belt drive, eventually transmits to the stubble cutter shaft. The dual drive structure could guarantee the stability and reliability of power transmission.



1. Cutting shaft 2.Self-driven shaft 3.Gearbox 4.Belt drive 5.Chain drive

Figure. 2 Drive System Design

The forward speed of the combined cultivating machine is 8～12 km/h usually, the revolving speed range of stubble cutter shaft is1000～1500 r/min. The diameter of self-driven disk is 800mm, the Equation (1) and (2) we can know that

the range of revolving speed is $53\mathrm{r/min} \le i \le 80r/\mathrm{min}$ and the range of transmission ratio is $12.5 \le i \le 18.86$.

$$\mathrm{n} = \frac{\mathrm{v}}{2\pi\ \mathrm{r}} \tag{1}$$

$$\mathrm{i} = \frac{\mathrm{v_M}}{n} \tag{2}$$

Where: n self -driven claws revolving speed , r·min-1, v —the linear speed of the self -driven claws fixed edge, m·min-1, $\mathrm{v_M}$ —stubble cutter shaft revolving speed,m·min-1, i —transmission ratio

According to the up transmission system designing scheme confirmed transmission ratio, gear tooth number, diameter of chain wheels and belt wheels after having consulted "Mechanical Design Handbook", the results are shown in Tab.2.

TABLE 2. TRANSMISSION RATIO AND SIZE PARAMETERS OF COMPONENTS

	Transmission ratio(i)	Big/small gear tooth number	Big/small chain wheel pitch diameter/mm	Big/small belt wheels Diameter/mm
Chain drive	1.58	27/17	-	-
First gearbox	3	-	386/128	-
Second gearbox	2	-	244/122	-
Belt drive	1.8	-	-	180/100

The revolving speed of stubble cutter shaft in two kinds of forward speed:

$$\dot{n}'_{\min} = n_{\min} \times (i_{12} \times i_{34} \times i_{56} \times i_{78}) \approx 904r \cdot \mathrm{min}^{-1}$$

$$\dot{n}'_{\max} = n_{\max} \times (i_{12} \times i_{34} \times i_{56} \times i_{78}) \approx 1365r \cdot \mathrm{min}^{-1}$$

According to the calculation, it can be seen that the range of self-driving wheel revolving speed is 53～80 r/min, stubble cutter shaft revolving speed range is 904～1365 r/min when the machine forward speed is 8～12km/h, which meet the requirement of the machine's common speed range, so the design of transmission is reasonable.

B. Stubble-breaking device

Stubbing is the main process of conservation tillage, stubble-breaking device is the key part of the combined cultivating machine, and it not only breaks the roots and clods in the soil, but also increases soil organic matter content and improves soil aggregate structure[17][18][19].

According to the movement mechanism of self-driven stubble-breaking device, stubble blades combined two kinds of movements that one is straight forward movement along with the machine, the other is circular rotation movement around the shaft.

$$\overline{v} = \overline{v}_m + \overline{v}_0$$

Where： $\overline{v}$ absolute velocity speed, r/min; $\overline{v}_m$ straight forward movement speed, r/min;

$\overline{v}_0$ circular rotation movement, r/min.

Established the rectangular coordinate system with the stubble cutter shaft center O(shown in Fig3) for the original center, the heading direction of the machine is x axis direction, the vertical ground up is y axis direction, the equation of stubble blades endpoints as follows.

$$\begin{cases} x = v_m t + R\cos\varpi t \\ y = \mathrm{R}\sin\varpi t \end{cases}$$

Where: ϖ -angular velocity of stubble cutter shaft, rad/s; v_m -the forward velocity of machine, m/s, R -turning radius of stubble blades，m.

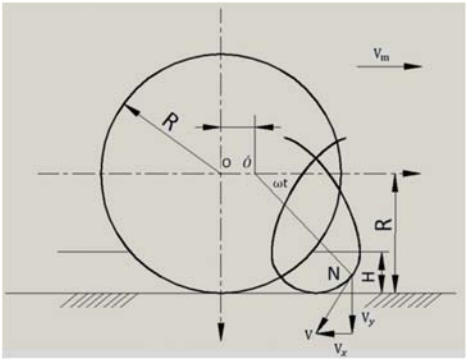


Figure. 3 Track diagram of a stubble blade endpoint

λ is called the stubble proportion, defined by the ratio between circular velocity of the stubble blades and forward velocity of the machine, as shown in Equation (3):

$$\lambda = \frac{v_0}{v_m} = \frac{R\varpi}{V_m} \tag{3}$$

N is supposed the stubble blade endpoint. As λ>1, the movement track of point N is trochoid,as shown in Fig.4. Take the one movement cycle track as the research object, assume the maximum horizontal distance points and the lowest point is A, B and C respectively. The speed of the absolute motion in horizontal direction of stubble blade endpoint is opposite to the heading direction of machine when it moves into the BC segment, cutting edge of the stubble blade, which will cut soil, break stubble, retroject the soil and broken stubble, achieve the goals that cutting stubble and cultivation. So it fully breaks the stubble blades, break the surface clods and underground stubble.

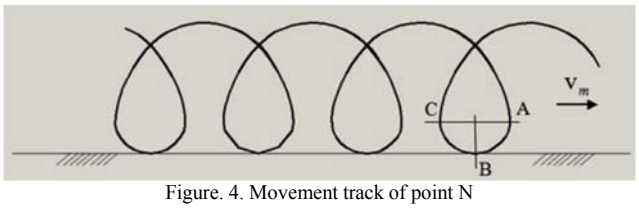


Figure. 4. Movement track of point N

This machine is equipped with the straight blade stubble cutters, as shown in Fig.55, the dimension parameters are shown in Tab.3. It has been widely used because of the good properties with cutting, smashing, throwing clods and simple manufacture. Blades must have enough resistance to wear since they work under the ground and cause intense friction; hence 65 Mn is selected [20].

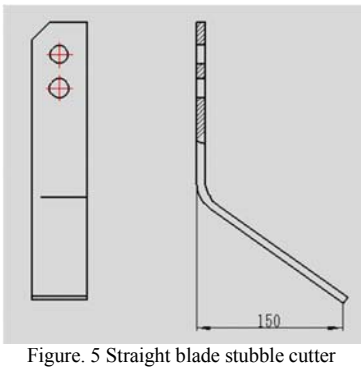
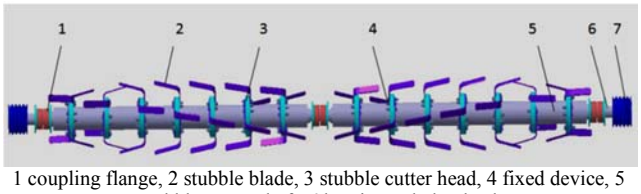


Figure. 5 Straight blade stubble cutter

TABLE 3 DIMENSION PARAMETERS

Items	Parameters	Items	Parameters
Bending angle/°	119	Bending radius/mm	40
Cutter shaft diameter/mm	580	Basil/°	17
Blade thickness/mm	1.5	Cutting width/mm	150

According to the kinematic analysis results and dimension[21]of stubble cutter shaft, it is composed of coupling flange, stubble blades, stubble cutter head, fixed device, stubble cutter shaft ,bearing and belt wheel, which were shown in Fig.6. Each stubble cutter shaft involves seven stubble cutter heads, whose diameter and rotation angle are 350 mm and 12.8°. Each stubble cutter head is staggered and symmetrical assembled four straight blade stubble cutters that fixed with bolts[22][23]. Width, depth and revolving speed of stubble are 4400 mm, 72 mm and 904～1365 r/min respectively.

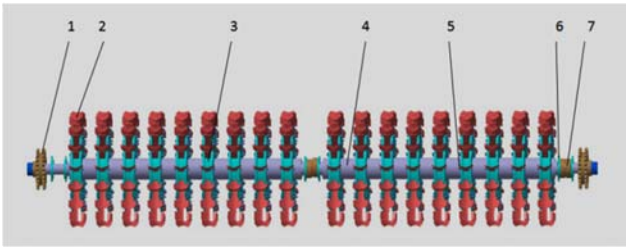


1 coupling flange, 2 stubble blade, 3 stubble cutter head, 4 fixed device, 5 stubble cutter shaft, 6 bearing, 7 belt wheel
Figure. 6 Stubble cutter shaft

C. Self-driven wheel

Grip hooks on self-driven wheel are embedded in the ground while working, the resistance force the self-driven wheel rotates, and power transmitted to stubble-breaking assembly by transmission mechanism. In the process of rolling cut, cutting stubble and mashing clods operation are completed.

Self-driven wheel is mainly composed by chain wheel, grip hook, self-driven disk, self-driven shaft, fixed device, coupling flange and bearing, which was shown in Fig.7. Each self-driven shaft staggered installed nine self-driven disks to enhance the working uniformity and stability, the self-driven disk's diameter is 800 mm, which is helpful to increase the arm of force and improve the conversion percent of kinetic energy[24][25].



1 chain wheel;2 grip hook;3 self-driven disk;4 self-driven shaft;5 fixed device;6 coupling flange;7 bearing
Figure. 7 Structural of Self-Driven Wheel

Self-driven wheel plays an important role in the part of power input of self-driven system. Its margin is hollow, the fixed portion of grip hook embed into it and ensure the strength by welding and fixed device, the parameters about self-driven wheel are shown in the Tab.4.

TABLE. 4 PARAMETERS OF SELF-DRIVEN WHEEL

Items	Parameters	Items	Parameters
Boundary dimension/mm	1040×100	Grip hooks amounts	16
Diameter of disk/mm	800	Grip hooks angle/°	22.5
Distance between the wheels/mm	245	Self-driven wheels Amount	9

IV. FIELD TEST

A. Preparation

The test will be conducted at a corn stubble height on the Heilongjiang *Hong Xing* farm during May 2 ~11, 2013, and the area is 2 hm2, the field without any treatment. The needed tools are a self-driven stubble-breaking combined cultivating machine(as shown in Fig.8), a Deer7820 tractor(with GPS system), platform scale(precision is 0.1 kg), a PMS710 soil moisture measuring instrument (the accuracy is ±2%), a TJS-450 soil strength measuring instrument (the accuracy is ±1%), a set oil measurement device(the error can be controlled within 2%), two rulers, two measuring tapes(range is 50 m) and some other tools, measured the physical parameters of the soil through the corresponding testing tools, the results are shown in Tab.5.

Figure. 8 Self-driven stubble-breaking combined cultivating machine

TABLE 5 RELATED PARAMETERS OF TEST FIELD

Test Items	Mean Values
Vegetation quantity kg/m3	2.0
Compatibility /KPa	36.5
Moisture content/%	19.8
Corn stubble height/cm	15～36

In order to measure the data accurately, draw lines to delimit the start and stop before the test, the area between the two lines is testing interval, the area before the start line is preparing interval witch to speed up the rated speed.

B. Test Index

B1. Measure of the cutting stubbles rate

The calculation method of the cutting stubble rate is confirmed according to the Mechanical Industry Standards of Rotary Cultivator Combined Operation (JB/T8401.2-2007). Choose a few points in certain stroke in the test field, and record the amounts as n, delimit an area of 1m×1m at each point and weigh the stubble in this area. Length that less or equal to 5 cm of straw is qualified, and the test data is introduced into formula (4) to calculate[26], and then the cutting stubbles rate is received:

$$P = \frac{M_h}{M_g} \times 100\% \tag{4}$$

Where: P—the cutting stubbles rate of n area,%; Mh—the quality of stubbles that length are less than 5 cm in n area, Kg; Mg—the total quality of stubbles in n area, Kg.

B2. Measure of the mashing clods rate

The calculation methods of cutting stubble rate and mashing clods rate are basically the same, and then get the cutting stubble rate.

$$E = \frac{M_a}{M_b} \times 100\% \tag{5}$$

Where: E —mashing clods rate within 10 cm surface in n area,%;Ma—the quality of the clods that size is less than 4cm within 10 cm surface in n area, Kg; Mb—the quality of all the clods within 10 cm surface in n area, Kg.

B3. Measure of the fuel consumption

The tractor drag the machine into the testing interval at a constant speed, and the measuring system began to work when the machine access to the starting line, measurement finished when the end of the machine contact the dead line[28]. During the test, the speed, breadth, time and operating mode have been measured by build-in GPS, and the record was down. According to the fuel consumption calculation formula (6), (7) to calculate[29].

$$K = \frac{G}{W} \tag{6}$$

$$W = 0.1BV \tag{7}$$

where: K—fuel consumption, kg/hm2; G—machine's fuel consumption of hours, kg/h; W—machine's working productivity, hm2/h; B—breadth, m; V—machine's operating speed, km/h.

C. Method

Divided the field into two parts, cultivated the corn residual field respectively by traditional rotary tiller produced by Ha Erbin Da Tian Agricultural Machinery Ltd. and stubble-breaking combined cultivating machine designed by this study. During the test, the tractor's dragging speed is 10 km/h, each group conducted four times. At last, each field chosen ten points to weigh the stubble and clods and calculated the cutting stubble rate and mashing clods rate through the upper method, read the fuel consumption, recorded results shown in Tab.6.

TABLE 6 WORKING PERFORMANCE

Time	Traditional Rotary Tiller			Stubble-Breaking Combined Cultivating Machine		
	Cutting Stubbles Rate/%	Mashing Clods Rate/%	Fuel Consumption/(L·Hm-2)	Cutting Stubbles Rate/%	Mashing Clods Rate/%	Fuel Consumption(/L·Hm-2)
1	87.22	76.00	20.3	91.60	85.12	18.5
2	88.09	76.29	22.6	93.11	84.33	17.8
3	86.38	74.87	21.0	92.43	86.04	17.0
4	87.55	73.92	22.1	92.06	84.63	18.3
Mean	87.31	75.27	21.5	92.30	85.03	17.9

From the test results, we can know that the cutting stubble and mashing clods rate of the self-driven stubble-breaking combined cultivating machine is 92.30% and 85.03%, improve 5.4% and 11.5% compared with traditional rotary tiller, fuel consumption reduces 16.7%. Meet the design requirements.

V. CONCLUSION

A kind of self-driven stubble-breaking combined cultivating machine has been designed, and the test result shows that the cutting stubbles rate reduced by 5.4%, mashing clods rate reduced by 16.7%, fuel consumption reduced by 16.7%, meeting the requirement of conservation tillage.

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