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RESEARCH ARTICLE

Development of multi-functional combine harvester with grain harvesting and straw baling

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Abstract

The decomposition and burning of straw results in serious environmental pollution, and research is needed to improve strategies for straw collection to reduce pollution. This work presents an integrated design of multi-functional rice combine harvester that allows grain harvesting and straw baling. This multi-functional combine harvester could reduce the energy consumption required for rice harvesting and simplify the process of harvesting and baling. The transmission schematic, matching parameters and the rotation speed of threshing cylinder and square baler were designed and checked. Then the evaluation of grain threshing and straw baling were tested on a transverse threshing cylinders device tes rig and straw square bales compression test rig. The test results indicated that, with a feeding rate of 3.0 kg/s, the remaining straw flow rate at the discharge outlet was only 1.22 kg/s, which indicates a variable mass threshing process by the transverse threshing cylinder. Then the optimal diameter, length and rotating speed of multi-functional combine harvester transverse threshing cylinder were 554 mm, 1590 mm, and 850 r/min, respectively. The straw bale compression rotating speed of crank compression slider and piston was 95 r/min. Field trials by the multi-functional combine harvester formed bales with height×width×length of 40×50×54-63 cm, bale mass of 22.5 to 26.0 kg and bale density 206 to 216 kg/m^3. This multi-functional combine harvester could be used for stem crops (such as rice, wheat and soybean) grain harvesting and straw square baling, which could reduce labor cost and power consumption.

Additional key words: *Oryza sativa* L.; transverse threshing cylinder; feeding rate; compression device; square bales; cost and energy consumption

Authors' contributions: Conceived and designed the experiments; technical and material support: ZT and YML. Performed the experiments; analyzed the data: ZT and CC. Wrote the paper: ZT. Critical revision of the manuscript for important intellectual content: YML.

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Introduction

There is production of about 2 billion tons straw world-wide every year (about 700 million tons in China), and this production poses adverse effects for agricultural production and the field environment. At present, only 7% of produced straw is used for industrial production of raw materials used in the production of paper pulp, furniture panels, and for biomass electricity generator. About 30% of straw is used to produce agricultural energy, including livestock feed, biogas, and agro-fuels. However, about 63% of straw is unused, and left to be degraded by field soil microorganisms or burned in the field. Excessive straw in field promotes the generation of crop pests and burning of excess straw causes serious haze. To avoid these problems, straw must be collected and transported away from the field (Anjum *et al.*, 2015; Kviz *et al.*, 2015). The current usage or treatment of straw in field is shown in Fig. 1.

Many recent studies have addressed the issues related to the problems of straw stacking in field. Summerell & Burgess (1989) investigated the decomposition and chemical composition of cereal straw and found that many elements could be beneficial for crop growth.

Figure 1. Current straw shedding and treatment in field: manual collection of straw (a), and mechanical straw baling (b).

The chemical components and decomposition of wheat straw could allow decreased fertilizer use (Marxen *et al*., 2016). The development of crop breeding technology and the use of genetically modified crops have led to increased usage of fertilizer (Becker *et al*., 2014). However, the more fertilizer is used, the more serious is the environmental pollution. Yang *et al*. (2015) reported that ditch-buried straw could increase soil nitrogen retention in a rice-wheat rotation system and also showed positive effects on soil carbon sequestration and crop yields. However, Mingze *et al*. (2016) reported that decomposition and chemical composition of cereal straw caused water pollution. Zhao *et al*. (2014) found that deeply buried straw retention could improve the soil content of organic matter and ensure a stable crop yield. Chen *et al*. (2016) investigated the effects of uneven vertical distribution of soil salinity under a buried straw layer on the growth, fruit yield, and fruit quality of tomato plants. Because long straw resists decomposition even when ditch-buried in soil, Guo *et al*. (2014) designed a stalk extrusion type dryer based on the principle of extrusion dehydration. Anjum *et al*. (2015) designed a wheat straw chopper to cut wheat straw. The use of chemical fertilizers and intensive pesticides and the over-exploitation of the soil have become less effective and also now face negative perception by the public (Mozner *et al*., 2012). The microbial decomposition of straw is attractive as an environmentally friendly option, but current approaches show limited efficacy.

Bortolini *et al*. (2014) presented an innovative multi-functional agricultural design that integrated three separate traditional implements used for hay raking, hay baling, and bale wrapping. Song *et al*. (2014) designed a small sugarcane leaf baler based on the open compression principle applied to a sugarcane leaf square baler. The crank slider-type compression mechanism and the specifications for crank length, compression rotating speed, and feeding rate were determined. Langer *et al*. (2015) investigated the adaptability between an agricultural tractor and large square baler and tested the increased power consumption of an agricultural tractor. Because of the high cost of straw collection, fewer farmers use a straw baler. Mathanker & Hansen (2015) investigated the relationship between harvesting cost and straw value and found that increasing bale density would decrease harvesting cost. Mathanker *et al.* (2014) determined a control strategy to maximize baler throughput rate and found that a large square baler operated at a ground speed of 6 km/h had a throughput rate of 35 Mg/h. Grisso *et al*. (2013) investigated the storage of grasses and the harvesting schedule for fill storage. Shinners & Schlesser (2014) investigated straw loss rate by a Hesston Model 4900 large square baler. After harvesting, combine harvester leaves a lot of straw in the field and manual collection is time-consuming and labor-consuming. The straw market value is often less than the mechanical harvesting costs of straw (Sokhansanj *et al*., 2014; Martelli & Bentini, 2015). The vast majority of straw is burned on-site, without prior transporting away from the field.

For the environmental sustainability of agricultural products, mechanized harvesting grain and baling straw is essential. The primary objective of this study was to develop a multi-functional rice combine harvester that allows grain harvesting and straw baling. This multi-functional combine harvester could reduce energy consumption and labor costs associated with grain harvesting and straw baling.

Material and methods

Multi-functional rice combine harvester

In order to develop a multi-functional combine harvester that allows both grain harvesting and straw baling, an appropriate sized combine harvester and straw baler must be selected. Additionally, the proper arrangement and powertrain of the multi-functional combine harvester was a key issue. The transmission schematic, matching parameters and the rotation ratio of threshing cylinder and square baler should be reasonable designed to avoid the center of gravity instability and insufficient power distribution. The multi-functional combine harvester was developed based on combine harvester DC50C and square baler MJSD-105. The threshing device from the combine harvester DC50C was a transverse single threshing cylinder Ø 554×1590 mm with 88 kW total power with Engineer 2200 r/min. The bale size in the square baler

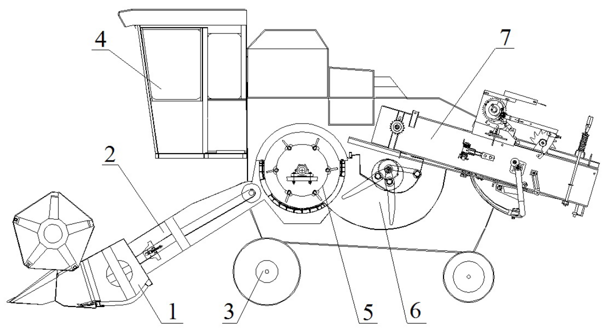

Figure 2. Multi-functional combine harvester with grain harvesting and straw baling. 1, combine cutting platform; 2, conveyor harrow; 3, travel wheel systems; 4, driving operation cab; 5, transverse single threshing cylinder; 6, grass fed aisle; 7, square bale.

MJSD-105 was 300×400×400-600 mm with a 36 kW towing tractor. For developing rational arrangement and powertrain of the threshing cylinder and square baler, the structure of multi-functional combine harvester was designed as shown in Fig. 2. The multi-functional combine harvester consist of combine cutting platform, conveyor harrow, travel wheel systems, driving operation cab, transverse single threshing cylinder and square bales. In harvesting, stems were cutted by combine cutting platform and feed into transverse single threshing cylinder device by conveyor harrow. After grain was threshed and separated by threshing cylinder, the straw was feed into square bales pass through grass fed aisle. The straw bale was formed in square bale device.

To match the operation variables of multi-functional combine harvester structure, the same structure size and variables of DC50C transverse single threshing cylinder were tested on a transverse threshing cylinders device tes rig. And the same structure size and variables of MJSD-105 square bales were tested on a straw square bales compression test rig. The rice threshing variable and straw baling variable were obtained using these two test rigs. The test results were the designing basic of the transmission schematic, matching parameters and the rotation ratio of threshing cylinder and square baler of multi-functional combine harvester.

Test rice and statistical analysis

The test rice (*Oryza sativa* L. cv. 'Zhen15') was grown in Jiangsu Province, China. The moisture content of the stalks was 51.8 to 54.2% and the grain moisture content was 27.5-31.6%. On the transverse threshing cylinders device tes rig, the threshing cylinder was driven by separate frequency conversion motors. During threshing, HAD-CYB-803S torque sensors (Beijing Westzh M & E Technol. Co., Ltd., China) measured the torque and speed at a measurement accuracy of 0.25% full scale and a frequency response time of 100 µs. The rice straw was threshed and separated by the threshing cylinder and then straw was discharged to the straw discharge aisle.

Freshly-cut rice (21 kg) was placed on a 7 m × 1 m conveyer belt at a linear speed of 1 m/s (with a constantly feeding rate of 3.0 kg/s). After the rice was threshed and the grain was separated through the grid concave, some grains were not threshed from the rice panicle (record as "un-threshed grain"), some grains were not separated from straw (record as "un-separated grain"), and some grains were crushed by the spike tooth (record as "broken grain"); together, these grains constituted the "total loss grain." Grains and straw were weighed on an electronic scale. The measurement accuracy of the scale was ± 0.1 g and its maximum range was 6 kg. The un-threshed grain ratio, un-separated grain ratio, and broken grain ratio were the mass percentage of un-threshed grain, un-separated grain, and broken grain.

The complete parameter estimation procedure and results of all tests were repeated five times to reduce the impact of random influence on the choice of validation set. Means ± SE were calculated using the same variables (n=5). The mean data were analyzed statistically using a factorial design in SPSS software (v. 13.0, SPSS Inc., CA, USA) and mean results were compared by least significant difference (LSD) post-hoc test at the 5% significance level ($p<0.05$).

Threshing cylinder test

A transverse threshing cylinders test rig was developed in 2013 in Jiangsu University Harvesting Machinery Laboratory. The test rig is shown in Fig. 3. Single threshing cylinders or double threshing cylinders of rice threshing and separating performance, grain loss ratio and power consumption could be tested on the test rig. In this paper, the transverse single threshing cylinder was

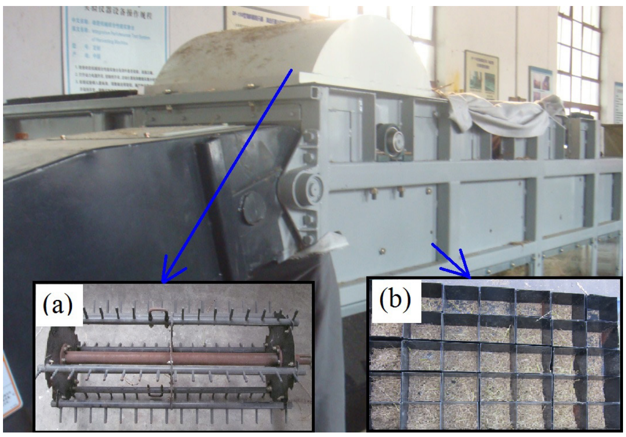

Figure 3. Schematic diagram of transverse threshing cylinders test rig: transverse threshing cylinder (a), and collection boxes under threshing cylinder (b).

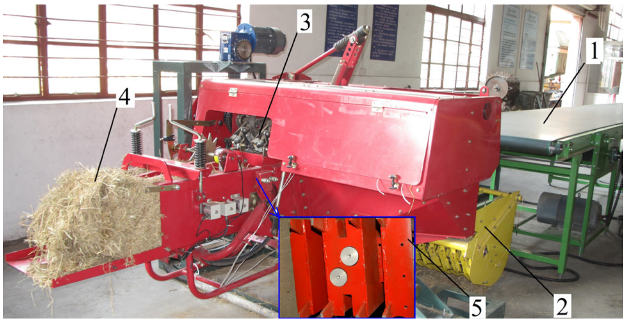

Figure 4. Straw square bales compression and baling test rig. 1, material conveyor; 2, straw pickup mechanism; 3, knotting device; 4, straw square bale; 5, pressure straw piston.

identical to the main body of multi-functional combine harvester. To investigate the threshing and separating capability of a transverse single threshing cylinder of combine harvester DC50C, the same structure size and variables of combine harvester DC50C transverse single threshing cylinder were set and developed on this test rig.

The diameter of the transverse single threshing cylinder was 554 mm and the length was 1590 mm. The threshing teeth were spike teeth. The rotation speed was 700 to 975 r/min, the threshing concave clearance was 25 mm, and the bar spacing was 100 mm. The grain collection boxes were fixed under the grid concave of the threshing cylinder to receive grains and short stalks that were separated through the grid concave, where 7 lines boxes were fixed along the axial direction of the threshing cylinder. The average flow rate of the mixture of grains and short stalks into the boxes was determined.

Straw square bales test

Straw bailing was essential means for multi-functional combine harvester to achieve straw collected from transverse single threshing cylinder. The structure size and variables of straw baling device should be obtained from a straw square bales compression test rig. A straw square bales compression test rig (Li *et al*., 2012) was developed in 2012 in Jiangsu University Harvesting Machinery Laboratory. The straw square bales compression test rig is shown in Fig. 4. The straw baling power comsuption, baling compressive force, bale density and straw square bale dimensions could be tested by this test rig. In order to investigate the characteristics of the square bales, the same structural parameters and operating parameters of the square bales MJSD-105 were carried out straw bailing experiments. The same structure size and variables of DC50C straw bailing device were set and developed on this test rig. The test was composed of a material conveyor, straw pickup mechanism, knotting device, straw bales, and pressure straw piston.

The electric motor total power in the square bales compression test rig was 22 kW. The sectional dimension of the pressure piston was 420 mm × 320 mm. To test the power and optimal parameters, a torque sensor was used to test the total input shaft power, and a pull and pressure force sensor was used to test the compressive force at compressed instant on the pressure straw piston. The mounting structure torque and pressure sensors of this test rig were shown in Fig. 5. Fig. 5a shows that the torque sensor was installed at total drive shaft connected to electric motor output shaft. This torque sensor could measure the total torque and speed of total drive shaft. Then the power comsuption of straw square bales compression test rig could be obtained by total torque and speed. The straw was collected by dial teeth and compressed by crank compression slider. So, the bale density was depending on compressive force of piston. Fig. 5b shows that the pull and pressure force sensor was installed on crank connecting rod of crank compression slider to measure the maximum compressive force of piston.

The power and the compressive forces were the most important indicators determined in this test rig. The compression rotating speed of the pressure piston and the straw feeding rate have been previously reported as important bale density indicators (Wang *et al*., 2009; Jin *et al*., 2011; Lotjonen & Paappanen, 2013). To test and analyze these bale density indicators, the

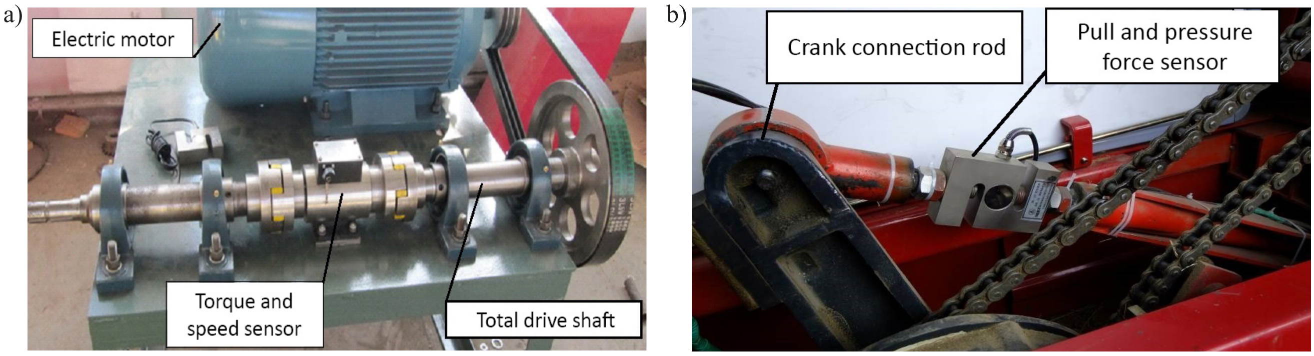

Figure 5. Mounting structure of torque and pressure sensor of straw square baling test rig: torque sensor on total drive shaft (a), and pull and pressure force sensor on piston (b).

Table 1. Device parameters and test results of transverse single threshing cylinder device

No.	Feeding rate (kg/s)	Threshing cylinder rotation speed (r/min)	Power of threshing cylinder (kW)	Total grain loss (%)
1	2.5	800	15.7±0.12	0.382±0.06
2	2.5	850	16.7±0.15	0.362±0.04
3	2.5	900	17.4±0.16	0.411±0.04
4	3.0	800	20.24±0.14	0.722±0.05
5	3.0	850	21.58±0.16	0.684±0.06
6	3.0	900	22.35±0.12	0.708±0.07

Table 2. Mass distribution of grain and stems in grain collection boxes

Axial test No.	Mass of total mixture (g)	Flow rate of total mixture (kg/s)	Mass of grains (g)	Remaining flow in device (kg/s)	Threshing and separating ratio (%)	Remaining grains on spike (%)
1	4099±44	0.59	3802±19	2.41	39.24	60.76
2	3247±59	0.46	2671±24	1.95	27.57	33.20
3	2598±155	0.37	1977±213	1.58	20.41	12.79
4	1261±200	0.18	737±76	1.40	7.61	5.18
5	605±106	0.09	219±13	1.31	2.26	2.92
6	507±46	0.07	174±26	1.24	1.80	1.12
7	144±43	0.02	75±15	1.22	0.77	0.35

straw threshed in the test was spread evenly on a 7 m material conveyor. From the material conveyor, the straw was picked up by the straw pickup mechanism and fed into the compression chamber by pressure straw piston. Straw square bales were shaped by layers of straw. When the straw square bale dimensions reached 300×400×600 mm, the square bale was bundled by a buckle binder. The structure and principles of square bales compression molding and the knotted rope were as described by Xiong *et al*. (2015) and Yin *et al*. (2015).

Results and discussion

Transverse single threshing cylinder

The feeding rate of transverse single threshing cylinder of combine harvester DC50C was 0-3 kg/s. When the combine harvester DC50C was harvesting in field, the feeding rate was an important indicator for achieving maximum harvesting efficiency. In order to obtain the threshed straw state parameters, rice feeding rates of 2.5 and 3.0 kg/s were used in the transverse threshing cylinders device test. The first threshing cylinder of transverse threshing cylinders test rig was equal to the transverse single threshing cylinder of multi-functional combine harvester. The testing variable and results are shown in Table 1. According to Table 1, the power consumption of the transverse first threshing cylinder was 15.70-17.40 kW, and the total grain loss was 0.362-0.411% at feeding rate of 2.5 kg/s. When the feeding rate was 3.0 kg/s, the power consumption and grain loss ratio were significantly increased to 20.24-22.35 kW and 0.684-0.722%, respectively. These results show that feeding rate of 2.5 kg/s was the optimal harvesting state. The total grain loss ratio was less than 0.411% and the power consumption of transverse first threshing cylinder was less than 19.77%, which was lower than the traditional threshing cylinders (Valentin *et al*., 2009; Osueke, 2011). When the feeding rate was 3.0 kg/s, the total grain loss and power consumption of the transverse first threshing cylinder were largely increased. The maximum feeding rate was an important indicator for structure size and variables designing of straw square bales device. The feeding rate of 3.0 kg/s and cylinder speed 850 r/min were used to design the transverse single threshing cylinder of multi-functional combine harvester. For testing the straw feeding rate at the point of straw discharge aisle, the grain distribution in the grain collection boxes was measured and is shown in Table 2.

Along the axial direction of the threshing cylinder, the mass of the total mixture separating through the grid concave decreased (except No. 2), but the cumulative mixture mass in the grain tank increased. The remaining grain ratio on the spike and the un-separating grain ratio decreased. The grain accumulation and remaining ratio throughout the process and the remaining flow rate

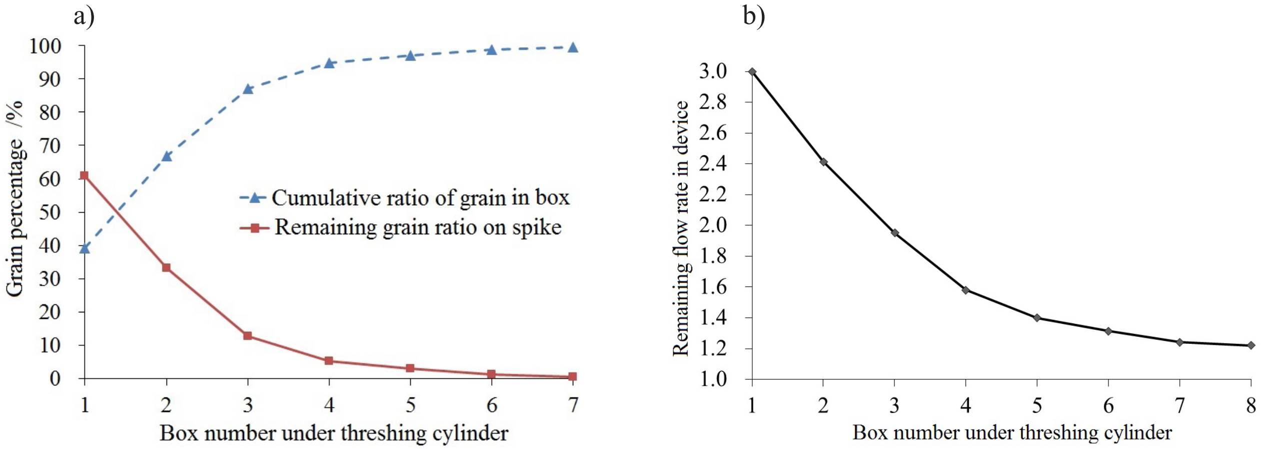

Figure 6. Trend of grain and flow rate in threshing process along threshing cylinder axial: accumulated grain and remaining ratio (a), and remaining flow rate in threshing process (b).

along the threshing cylinder axial were determined based on the values in Table 2. The grain accumulation and remaining ratio in process is shown in Fig. 6a. The remaining straw flow rate along the threshing cylinder axial was calculated as shown in Fig. 6b. According to Fig. 6, the grain separating ratio was different in every box. The grain separating ratio of 1-3 boxes was greater than others, indicating stronger threshing and separating capability. The threshing and separating capability of 5-7 boxes were lower than in other parts. The cumulative ratio increased along the threshing cylinder axial. The threshing and separating process occurred with variable mass and the grain and straw were separated into the grain tank. At the end part of the threshing cylinder, the rate was only 1.22 kg/s, lower than the feeding rate of 3.0 kg/s, which indicates a variable mass threshing process by the transverse single threshing cylinder. In traditional threshing cylinder design and investigation, the feeding rate decreasing law was ignored (Singh *et al*., 2008; Golpira *et al*., 2013). Tang *et al*. (2013) indicated that the straw flow rate decreased at the outlet of longitudinal-flow device. The decreased straw flow rate was an important indicator for straw crushed.

The feeding rate was 3.0 kg/s but the remaining flow rate was 1.22 kg/s after threshing, suggesting that the design of the square bales MJSD-105 should be based on a straw feeding rate of 1.22 kg/s. Based on the results of the spike teeth transverse single threshing cylinder, a feeding rate 3.0 kg/s provided the best threshing capacity. The threshing cylinder was developed with the same structure and dimensions of the transverse first threshing cylinder test for multi-functional combine harvester.

Straw square bales compression

According to the results of the threshing cylinder device test rig, there was only 1.22 kg/s straw flow rate at the threshing cylinder discharge outlet, even though the feeding rate was 3.0 kg/s at feed inlet. For this reason, the straw flow rate of 1.22 kg/s for the square bales compression test was next studied. The mechanics of making the square bales were determined previously and the compression straw technology and rope deduction technology were obtained from Yin *et al.*´s (2011; 2015) works. The compression rotating speed was based on transmission design of the multi-functional combine harvester. Feeding rates of 1.0 and 1.22 kg/s were used for the pilot testing to determine the power of square bales testing, the compressive force of the piston, the bale density influenced by compression rotating speed, and the straw feeding rate, as shown in Table 3. According to the data presented in Table 3, the adjustment range of compression rotating speed was 85-105 r/min, which was used for the transmission design of the multi-functional combine harvester straw square bales device. With increasing rotating speed, the compression power consumption and compressive force of crank connecting rod also increased. The bale density remained stable and the variation range was 125.20-126.99 kg/m^3. With a compression rotating speed of 85-105 r/min, the compression power consumption and compressive force were relatively stable. Compression rotating speed values outside this range would result in large fluctuations of compression power and compressive force. Using bale density as an index, the compression rotating speed of the bale shaft at 95 r/min resulted in a higher packing density with a straw feeding rate of 1.22 kg/s.

The square baler was developed based on the testing results and structural parameters of the straw square bales compression test rig. A virtual prototype of the square baler was generated using Pro/E software and is shown in Fig. 7. To allow additional rational design of the threshing cylinder and square baler, the threshing cylinder model and virtual prototype of square baler were assembled.

Table 3. Performance of square bales test at different compression frequencies

Feeding rate (kg/s)	Compression rotating speed (r/min)	Power consumption (kW)	Pressure force of crank connecting rod (kN)	Bale density (kg/m^3)
1.0	85	3.21±0.12	11.06±0.24	125.20±0.64
1.0	90	3.46±0.14	12.31± 0.27	125.96±0.65
1.0	95	3.60±0.17	12.43±0.34	126.99±0.98
1.0	100	4.33±0.15	13.62±0.39	126.83±0.84
1.0	105	5.06±0.14	14.52± 0.24	125.93±0.67
1.22	85	3.64±0.14	14.96±0.29	125.84±0.67
1.22	90	4.01±0.13	12.24±0.28	126.06±0.76
1.22	95	4.29±0.16	13.96±0.31	126.87±0.84
1.22	100	4.86±0.13	13.39±0.22	125.10±0.91
1.22	105	5.36±0.19	14.01±0.28	125.95±0.96

Transmission of threshing cylinder and square baler

Limited by structural constraints and the center of gravity of the multi-functional combine harvester, the engine was installed at the end of the harvester. The output speed of the engine was 2200 r/min, which should allow multi-stage reduction for the threshing cylinder shaft and the square baler shaft. The transmission structure and path from the engine to the threshing cylinder and the square baler are shown in Fig. 8.

Because the output of engine speed (2200 r/min) was much greater than the input speed of the pressure piston, dial pitchfork, and bale shaft, triple reduction gearing was developed to slow down the output of engine speed. The effect of an inertia flywheel was to store energy and to allow normal operation of the gearbox.

The drive ratio was 9.12; it was calculated by dividing the values of the two transmission wheel rotation speeds. Based on the triple reduction gearbox and transmission schematic, a rational threshing cylinder rotating speed of 850 r/min and rational piston crank rotating speed of 95 r/min were obtained. This transmission structure and triple reduction gearbox were developed to be used in the multi-functional combine harvester.

Table 4. Characteristic parameters of baler

No.	Bale size (cm) (height × width × length)	Bale mass (kg)	Bale density (kg/m^3)
1	40×50×63	26.0	206
2	40×50×57	24.0	210
3	40×50×55	23.4	211
4	40×50×54	22.5	208
5	40×50×56	24.2	216

Multi-functional combine harvester

According to the test results, the virtual prototypes of the threshing cylinder, square baler and the multi-functional combine harvester were developed (manufactured by Jiangsu Nantong Cotton Machinery Co., Ltd.). Based on the transmission schematic, the centroid of the multi-functional combine harvester was more balanced. Ground clearance was the same as in the conventional combine harvester with a lower side feeding straw component of the square baler. The No-load still total mass of multi-functional combine harvester was 4946 kg. The developed multi-functional combine harvester is shown in Fig. 9. Using the model shown in Fig. 9, rice harvesting and bale testing was tested in December 2015. The characteristic parameters of bale size, bale mass, and bale density were tested with a feeding rate of 3.0 kg/s. The test results and bale parameters are shown in Table 4. According to the data presented in Table 4, the height × width × length of bale was 40×50×54-63 cm. The length of bale varied from 54 to 63 cm, due to the rebinding of the bale. This bale size was suitable for small harvesters and small plots (Yang *et al*., 2007; Li *et al*., 2013). The

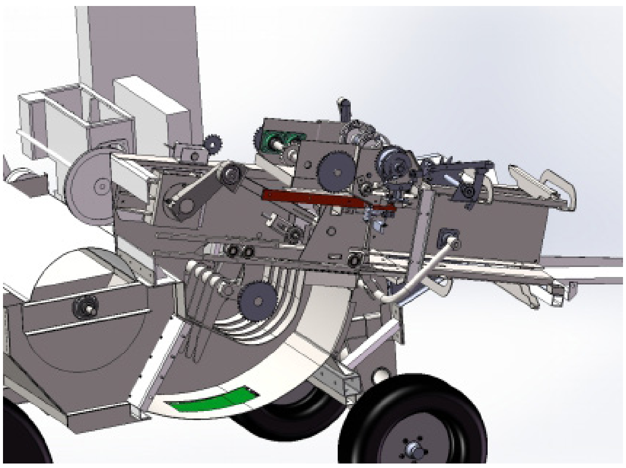

Figure 7. Virtual prototype of square baler

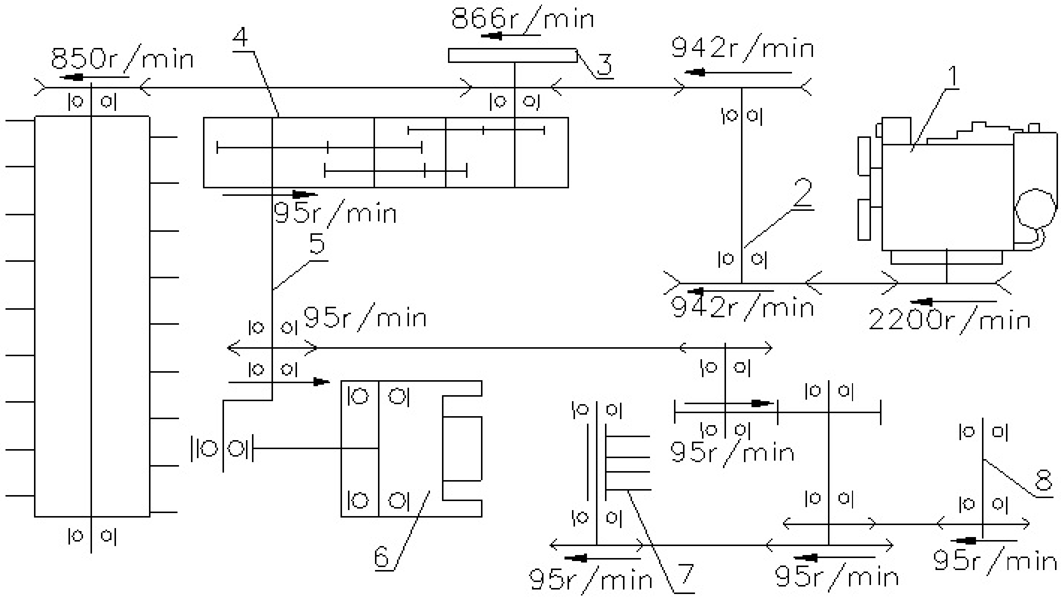

Figure 8. Transmission schematic of threshing cylinder and square baler. 1, engine; 2, engine intermediate shaft; 3, inertia flywheel; 4, gearbox; 5, shaft; 6, pressure piston grass; 7, dial pitchfork; 8, bale shaft. The direction of the arrow (⇐ or ⇒) represents the direction of rotation; ⟷ represents the sprocket wheel; >—< represents the belt pulley.

bale mass was between 22.5 and 26.0 kg. This bale mass fluctuation was due to variation in bale size and straw moisture content. The bale density baling by this multi-functional combine harvester was from 206 to 216 kg/m^3, which was less than the bale density 470 kg/m^3 of multi-functional haymaking agricultural machinery (Bortolini *et al*., 2014). In China, Wang *et al*. (2009) developed a large rectangular baler, with a bale density of 190 to 210 kg/m^3. Jin *et al*. (2011) developed a straight baler device with a bale density of 172 kg/m^3. The bale mass, bale size and bale density of the multi-functional combine harvester were similar to Chinese existing balers. The power consumption and compressive force of piston of Chinese straw square baler device were lower than the values found by Bortolini *et al*. (2014). Overall, this multi-functional combine harvester was demonstrated to be functional for rice harvesting and straw square bale compression.

Figure 9. Overall appearance of multi-functional combine harvester

In summary, rich grain has been traditionally harvested with the straw left in the field, followed by collection and baling of the straw days later. This is a time-consuming and labor-consuming process by either manual or mechanical collection, and often the straw market value is lower than the costs of mechanical harvesting. Use of this multi-functional combine harvester that allows concurrent grain harvesting and straw baling could reduce overall energy consumption and reduce the cost of harvesting. With a feeding rate of 3.0 kg/s, the remaining flow rate at straw discharge outlet was only 1.22 kg/s, which indicates a variable mass process in rice threshing. In order to arrange and match the rates for the rice threshing and straw compression device, the diameter, length and rotating speed were set to 554 mm, 1590 mm and 850 r/min, respectively. The compression rotating speed of the square bale device was 95 r/min. Field trials of this multi-functional combine harvester resulted in bale sizes of 40×50×54-63 cm (height×width×length) and the bale mass of 22.5-26.0 kg. The bale density baling by this multi-functional combine harvester was 206-216 kg/m^3. This multi-functional combine harvester can perform both grain harvesting and straw square baling to reduce labor cost and power consumption in stem crops (such as rice, wheat and soybean) harvesting.

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