Current status and prospect of research on combine harvester header for rape

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Abstract. Rapeseed is one of the most important oil-bearing crops in China. Because of its poor efficiency, the planting area is in a trend of declining year by year. In order to change the status quo of low efficiency and stimulate farmers' enthusiasm for planting oilseed rape, it is of great significance to vigorously promote the mechanized harvest in the process of rapeseed production. The rape header is an important part of the rape combine harvester. It is different from the header structure of common rice and wheat combine harvesters, and the header depth is larger. At the same time, in order to solve the problem of dense branches and cross-linking of rapeseed, in addition to the main cutter, reel and screw conveyor, the rape header also needs to be equipped with a vertical splitting cutter on the side. In this way, the entangled branches are cut and the loss of shattering can be reduced. Head loss accounts for a considerable proportion of the total loss during the rape harvest. By reasonably configuring the structure of the rape header and optimizing the working parameters, the vibration of the header and the power consumption of the header can be reduced, and the work efficiency can be improved. It is of great significance to reduce the mechanical harvest loss of rape and increase the efficiency of rape planting. This article introduces the current status and progress of the research on the working structure of the rape header at home and abroad. Point out the existing problems and put forward suggestions for the development of rape header in the future.

1. Introduction
Rapeseed is one of the oil crops with the largest planting area and the most extensive planting area in China[1]. Its annual planting area accounts for 25% of the world's total planting area of rape seed[2]. Rape not only provides more than 4.5 million tons of edible vegetable oil for China, but also provides more than 6 million tons of feed protein for animal husbandry. Therefore, the development of the rape industry is an important aspect of ensuring China's food security. At the same time, rape has the advantage of being a biodiesel and is considered as an ideal raw material for biodiesel[3].

Rape occupies a pivotal position in domestic grain and oil production, directly related to people's living standards, dietary structure and energy environment security[4]. However, in recent years, farmers lack the enthusiasm for planting rapeseed. In some areas, the farmland is idle in winter. According to the data provided by the seed sales terminal, rapeseed planting area in China has declined in recent years.

The low efficiency of rape production is the root cause of the decline in the planting area of rape in my country. One of the main problems that farmers face is the low popularity of rape production machinery[5]. On the one hand, farmland in China is seriously fragmented, and some areas are hilly and mountainous areas. This pattern is difficult to carry out mechanized large-scale operations. On the other hand, restricted by the growth characteristics of rapeseed itself, its plant is tall, the stalk is thick,
the branches are entangled seriously. The siliques are severely cracked during the harvest, which causes excessive mechanical harvest losses[6][7]. Due to the low efficiency of rapeseed cultivation, farmers are unwilling to invest too much money in mechanization.

Under the same test conditions, the field harvest effect comparison test was conducted on the existing domestic rapeseed artificial harvest and mechanical harvest. The results show that the loss rate of manual harvesting header is the largest, and the labor intensity is high, which is the most undesirable. It is of great significance to promote the mechanized harvest of rapeseed[8].

2. Research status

The combine harvester full-feed horizontal header is mainly composed of reel, cutter and screw conveyor. It completes the cutting and conveying of crops, which is the basis for the normal operation of the combine harvester. The structure of the combine harvester header often varies according to the type of crops harvested. The characteristics of rapeseed plants are different from rice and wheat. In order to reduce the loss of the harvester, extensive research has been conducted on the header of rapeseed harvester.

2.1. Research related to reel

The reel is used to push the crop to the cutter for supporting cutting, and further push the cut crop to the header conveyor. Rapeseed stalks are rigid, their branches are severely entangled, which is easy to cause loss of pod burst. The reel used in the rape header should be optimized for the characteristics of the rape crop.

Xu Huquan optimized the main parameters of the reel of the new type of rape harvester in terms of the speed of the reel, the diameter of the reel, the vertical and horizontal positions of the reel center, and the form and number of reel teeth[9].

The installation position of the reel for rape harvesting is different from that for rice and wheat harvesting. Some scholars have conducted research on this aspect[10]. In the traditional design, the reel has an extension S, which depends on the crop. But according to calculations, S is always positive. When harvesting rice and wheat, the maximum extension of the reel can reach 330mm. When rapeseed is harvested, the rape stalks have been hit before they enter the header, and the grains will easily fall outside the header, causing loss of the header. When designing the rape header, the reel should be designed with a receding amount. The position of the central axis of the reel is reduced to the cutter to effectively reduce the harvest loss of the header.

Ren Wentao assumes that the horizontal sub-velocity of the paddle is zero when the paddle touches the plant, and the crop rebounds when the paddle moves away from the tip of the crop. Based on the above assumptions, he deduced the range of the forward movement of the reel in the process of harvesting fallen crops. With the aid of computer simulation, the influence of speed ratio and stubble height on the forward movement of the reel is analyzed. Similar methods can be used in the design of rape header[11].

Wang Binbin puts forward an optimized design scheme for the reel of rape header by designing and calculating key parameters[12]. The reel power is provided by an adjustable speed hydraulic motor or electric motor, which increases the versatility of the header while avoiding resonance. Rapeseed stalks are thick and rigid, and the supporting effect of the reel is small. The position of the reel should be moved back so that the plucked grains fall into the header as much as possible. In order to ensure a good push effect of the reel to the rape plant after cutting, the height of the vertical position of the reel center should be greater than or equal to the sum of the height of the center of mass of the rape plant and the radius of the reel. The branches of rape are entangled with each other, and it is easy to produce burst pods under the action of the reel teeth and cause losses. Therefore, the number of reel teeth should be appropriately reduced.

Chen Xing further quantified the optimization of the reel of the rape header[13]. He pointed out that reducing the number of reel gears, lowering the reel speed, and increasing the height of the reel is the key to solving the problem of burst pod loss. The design example reduces the number of reel teeth
from 70 to 36; the speed is reduced to 15-20 r/min; the height adjustment range of the reel is increased to 1.5-1.8 m. In actual work, it is best to adjust the height to just touch the tip of the plant. For the combine harvester equipped with this header, the loss rate of the header during work can be reduced to about 2%.

Wu Wenjie used the horizontal position of the reel, the vertical position of the reel, and the speed of the reel to perform a three-factor three-level quadratic regression orthogonal test to analyze the influence of each factor on the harvesting effect[14]. The results show that the horizontal position, vertical position and rotation speed of the reel have a certain influence on the loss rate, and only the reel rotation speed has a significant influence on the feeding amount. The order of significant influence on the loss rate of the header is the vertical position of the reel, the speed of the reel, and the horizontal position of the reel. Experiments were carried out under the optimal working parameter combination, and the relative error between the measured value and the optimized value of the header loss rate and the feeding amount was less than 5%.

Dong Yueliang conducted a theoretical analysis on the structural characteristics of the rape harvesting header[15]. Single factor tests were performed on the reel speed, machine forward speed, the vertical position of the reel relative to the cutter and the horizontal position of the reel relative to the cutter. On this basis, orthogonal experiments are carried out for the parameters that have a greater impact on the header loss. According to the size of the range, it can be seen that the machine forward speed has the most significant impact on the loss of the header, followed by the reel speed and the vertical position of the reel shaft relative to the cutter. The DPS data processing system is used to process the test results, the regression equation of three factors is established, and the parameters of the model are optimized to obtain the best working parameters and structural parameters.

Qi Bing established a mathematical model of the reel's forward movement range[16]. He refined the analysis and then improved the reel's installation position constraint formula, and proposed the concept of "minimum forward movement". The Adams was used to establish a parametric virtual prototype of the reel with key motion parameters and structural parameters as design variables, and to simulate the forward range of the reel. The forward movement range of the reel that meets the three constraints of vertical insertion, stable pushing and no rebound under different wheel speed ratios is obtained.

According to the multi-branched "tree-like" characteristics of rapeseed, Yang Yi found that when the spring teeth are in contact with the plant, the oblique insertion method helps to reduce the collision loss of the header[17]. When leaving the plant, the angle of inclination is reduced to close to 0° to prevent entanglement. Based on this, an oblique-insertion reel is designed to meet the ideal working trajectory of the elastic teeth. Its structure is shown in Figure 1. Kinematic analysis shows that when the grazing speed ratio λ > 1, the trajectory of the bat and the end of the spring tooth is a trochoidal line, and there is a buckle trajectory, which can push the crop into the header. The apex trajectory of the spring teeth is under the side of the bat trajectory during the contact with the plant, indicating that the spring teeth are inserted obliquely. The apex trajectory of the spring teeth is below the bat trajectory at the stage of leaving the plant, indicating that the inclination of the spring teeth is gradually reduced, which can prevent entanglement.
In order to quickly obtain the movement trajectory and movement status of the reel under different motion parameters, Yang Shuchuan used five methods including M files under MATLAB, Simulink, GUI, LABVIEW and signal modules under AMESim according to the mathematical model of the reel. Simulated the reel's movement trajectory. According to the physical model of the reel, the SimMechanics module library under MATLAB and the plane mechanism module library under AMESIM are used to simulate the reel motion trajectory[18]. The results show that these methods can accurately simulate the reel's motion trajectory.

Xiao Yangyi performed kinematics simulation on the virtual prototype model of the reeling device[19]. The drive is established by setting 5 sets of different data for the forward speed, the circular motion speed and the reel speed ratio λ. The kinematics simulation analysis is performed on the reel to obtain 5 sets of motion trajectories. The results show that only when the reel's speed ratio λ>1, the motion trajectory is a trochoidal line, forming a closed buckle so that the spring teeth can push the crop stems backward. When the speed ratio is 1.55, the effect of the reel is closest to the best effect, and unnecessary drop loss can be avoided at this time. Both the maximum and minimum forward distance of the reel increase with the increase of the reel speed ratio.

Hirai studied the mechanical interaction between the combine harvester's reel and crop stalks[20][21]. The research results show that considering the model of crop ears and considering the effect of vertical component is useful for studying the interaction between reel and crop, which can increase the accuracy of the analysis of the deflection force. At the same time, the dynamic response of the quasi-static stalk bending of the combine harvester's reel is analyzed. The horizontal and vertical reaction forces of rice and wheat stalks under five different loading speeds were studied. The collected acceleration test results show that the positions of the positive peak of the horizontal reaction force and the negative peak of the vertical reaction are consistent with the positions of the negative peak of the horizontal acceleration and the positive peak of the vertical acceleration respectively. Which means the peak value at high loading speed is formed by the inertial force of the crop stem.

Cui Yong designed an automatic control system for the reel condition of the combine harvester, which realized the effective control of the reel wheel speed[22]. The reel speed control system in this design uses three-phase alternating current as the power source, combined with 87C196KC microcontroller to form the core control system. The design also includes components such as voltage stabilizing circuit, synchronization circuit, and amplifying circuit to achieve effective control of the reel speed.

Liu Jianghua has improved the reliability and adaptability of the reel of the electric drive combine harvester[23]. He takes P89C51RX2 series single-chip microcomputer system as the core. By collecting the walking speed signal, the position signal of the reel, the position signal of the hydraulic cylinder of the header, and the height signal of the crop, the position and speed of the reel are automatically controlled by the electro-hydraulic proportional reversing valve and the inverter drive motor.
Wang Shuqing designed the combine harvester header parameter adjustment device to realize the automatic adjustment of the combine harvester header height, reel height, front and rear position of the reel and the speed of the reel[24]. The sensor module detects the parameters of the header and the operating speed, and inputs the detection signal to the PLC control unit for processing. At the same time, the control signal is sent to the corresponding header drive module after being judged and processed by PLC to realize the electric adjustment of header parameters. Tests show that the relative error of the header parameter adjustment, the relative error of the operating speed detection, the response time of the automatic adjustment of the reel speed, the adjustment time and the control accuracy can all meet the expected requirements.

2.2. Research related to cutters
The rape header cutter includes a horizontal main cutter and a vertical separating cutter. The main cutter is used to cut the rape stalks, and the separating cutter is used to separate the entangled branches to reduce the loss of grain shattering.

2.2.1. Research related to main cutter. Compared with rice and wheat, rape stalks are thicker and more rigid. The current research on the main cutter of the rape header is mainly to change the form of cutter, such as the use of a disc cutter[25]. In addition, there are also some researches on the drive mode of the cutter and the physical characteristics of the rape stem.

In order to reduce the loss of the header of the rape combine harvester, Li Zhongkai designed a sawtooth disc cutter with an eccentric arc blade curve[26]. Its structure and cutting process are shown in Figure 2 and Figure 3. The blade rotates with the cutter head at high speed. In the critical cutting state, the huge pressure generated by the point contact between the saw teeth and the stem can quickly tear the stem. When the blade starts to cut, the cutting edge is in linear contact with the rape stalk, and the continuous serration can effectively clamp the stalk and reduce the cutting vibration.

![Figure 2. Diagram of the structure of the cutter head and the blade.](image)
Zhang Beibei designed a rape loop chain cutter whose structure is shown in Figure 4. The cutting edge curve of the movable scimitar adopts an involute design, and the fixed blade is a triangular single-sided serrated design. The scimitar cooperates with the double fixed blade to realize the one-way circulation double support cutting. During operation, the rape stalk enters the cutting area between the scimitar and the fixed blade, and the scimitar in high-speed motion completes the cutting of the stem under the support of the upper and lower fixed blades. The test of the influence of cutting speed and cutting height on cutting force and cutting power shows that with the increase of cutting speed, the cutting force and cutting power decrease. Field test results show that the cutting speed of the cutter is 2.0 m/s and the cutting height is 400 mm, the cut is flat, the section is neat, and there is no tearing phenomenon.

Zhang Jumin proposed a brand-new improvement plan for the current rape combine harvester cutter, using a high-speed rotary disc cutter to replace the traditional reciprocating swing cutter, and its structure is shown in Figure 5. While rotating at high speed, the movable cutter head is driven by a swing mechanism to reciprocate left and right at low speed. The high-speed rotating disc blade can achieve "small feed" or even "micro-feed" cutting, and the small blade teeth can achieve an uninterrupted cutting effect on rape stalks. Rotary disc cutters can be connected in parallel through mechanisms to meet different cutting width requirements. The form shown in Figure 6 is a parallel connection of 4 disc cutters.
Liu Zhengming designed and tested the header of the rape combine harvester according to the characteristics of the hilly areas in Sichuan[29]. The main cutter of the header adopts a double-acting blade, which can reduce the vibration of the header while enhancing the cutting effect. A lower cutting blade is set at the rear and lower part of the header, and the lowering and lifting are completed by operating the lifting of the header. The lower cutting blade is used to cut the rape stalks, which is convenient to organize the harvested field.

Ran Junhui designed a dual-action cutter planetary gear drive to balance the cutter's inertial force and weaken the impact resistance generated by cutting[30]. Its structure is shown in Figure 7. The active rack and the passive rack always make reciprocating linear motions in opposite directions, so that the upper and lower cutters complete the reciprocating cutting motion. Analysis shows that the cutter has high cutting continuity, stable load, and little disturbance to rape stems. When the cutting speed of the cutter is in the range of 1.2 ~ 1.6 m/s, the cutter saves more power consumption than the crank-connecting rod single-action blade cutter and the crank-connecting rod drive double-action
blade cutter. The results of no-load vibration test and field test show that the cutter has a better vibration damping effect than the crank-connecting rod single-action blade.

![Figure 7. Structural diagram of planet gear driver of double-acting cutter](image)

University of Bologna, Italy A. Guarnieri, C. Maglioni studied the centralized mass model of the reciprocating cutter driven by the crank-link mechanism and calculated the motion equation[31]. It is found that the vibration of the reciprocating cutter is mainly caused by the instability of the motion and torque cycle, and its influence is far greater than the influence of the cutter inertia force on the system. In addition, they also found that the cutting damping of the cutter decreases as the operating speed increases.

Wang Jiankang established the kinematics model of the reciprocating cutter transmission mechanism, which is a spatial crank connecting rod-rocker slider transmission mechanism[32]. The motion acceleration of each main component is analyzed, and the inertial force expression of the main component is obtained by solving the equations of the restraining force between the motion pairs in the mechanism. He pointed out that the inertial force of each component in the mechanism is an important factor causing impact and wear, so the inertial force should be reduced as much as possible. Ren Shuguang improved the cutting drive system and header of the 4lz-3.5 rice combine harvester to make it used for rape harvesting[33]. The reasons for the inertia force on the flywheel and cutter when the mechanism moves are analyzed. At the same time, the influence of cutter inertial force and cutting impact force excitation on the amplitude, speed and acceleration of the header is studied. By adding a counterweight on the flywheel and improving the design, the center of mass of the connecting rod is moved to the flywheel crank pin, which can reduce the inertial force. Tests show that the improved design can reduce the vibration speed and acceleration, and the amplitude by about 11%, which greatly improves the working performance of the harvester and reduces the harvest loss.

Wu Mingliang conducted a single-factor and multi-factor cutting force test on the self-made cutting test bench for the main influencing factors of cutting force of rape stalk cutting method, stalk cutting position, cutting blade form and cutting speed[34]. The cutting test bench is shown in Figure 8. The up and down movement of the blade holder simulates the effect of the reciprocating cutter. The impact of the cutting force is simulated by the operating speed of the blade. Tangent and sliding cut are realized by adjusting the blade and blade installation angle. The single factor test shows that the cutting force of the serrated blade is smaller than that of the smooth blade, and the cutting method is the most labor-saving by sliding. The higher the cutting speed, the higher the height of the stem from the ground, and the smaller the cutting force. The multi-factor experiment showed that the cutting
force was the smallest when the serrated blade was used for sliding cutting at a height of 400 mm above the ground of the rape stalk.

![Diagram](image)

**Figure 8.** Sketch of cutting test-bed.

The shock stress wave generated by the main cutter of the rape header is transmitted to the pod through the stalk. When the stress amplitude exceeds the crack resistance limit of the pod, the seeds fall off and cause harvest loss. Ren Shuguang analyzed and studied the viscoelastic properties of rape stalks on the propagation of stress[35]. The viscosity coefficient and elastic modulus of rape stalks were measured by experiment, and its creep and relaxation curves were obtained. The energy consumption curve during the experiment shows that the rape stalk has both elastic solid properties and viscous fluid properties. He proposed that the three-element solid model can more accurately describe the viscoelastic characteristics of the stem, and the model can reflect the instantaneous elasticity, creep and relaxation of the stem.

2.2.2. Research related to separating cutter. The rape header is different from the rice and wheat header. The former uses a vertical cutter installed on the side of the header to cut the branches of the rape and divide the rape into the harvested area and the unharvested area. Which ensures the normal operation of the harvester. The vertical cutter is also known as the separating cutter. However, the vertical cutter will cut off the pods and disturb the plants during the forced branching process, resulting in the loss of grain falling and splashing. At present, the head loss of rapeseed is the main source of rape harvest loss. Among them, the loss of the vertical cutter accounts for more than 40% of the loss of the header[36][37]. Therefore, it is necessary to further optimize the vertical cutter to improve its operational stability and adaptability.

Wu Fuliang conducted an experimental study on the blade of the double-action blade separating cutter[38]. Comparative experiments show that the cutting effect of thick branches is the most ideal when a small blade with a cutting stroke of 76.2 mm is used. The shearing opening area is larger, and the cutting performance of branches is better. The large blade with a cutting stroke of 76.2 mm and the small blade with a cutting stroke of 50 mm produce smaller cutting openings. They can only cut the direct seeding rapeseed with thin stems, and it is not easy to cut the thick branches with large shearing angle and shearing force. In this case, the towing belt will break, which not only increases the loss of the header, but also affects the splitting effect. The blade cutting analysis is shown in Figure 9.
Dong Jiandong launched relevant research and design on the number, form, horizontal distance and height of the separating cutter[39]. He pointed out that although the installation of separating cutters on both sides is conducive to clearing the road, its utilization rate is low and the structure is complicated. Therefore, the single-sided vertical cutter structure is widely used. Under difficult harvesting conditions such as harvesting lodging crops, a single-acting blade cutter with a low cutting speed is likely to cause pulling loss, and the double-acting blade with an amorphous blade is better than a single-acting blade. At the same time, for double-acting blades, half-pitch-stroke double-acting blades (s=0.5t) have better overall performance. Single-stroke double-acting blade (s=t) can be used for high-speed harvesters after appropriately reducing the cutting stroke. The installation position of the separating cutter needs to have a certain amount of extension relative to the main cutter to avoid pulling the rape in the area to be cut when the harvester is operating, and the amount of extension should be close to the radius of the rape canopy. In the case of meeting the cutting requirements, in order to reduce the weight of the header and reduce the vibration of the header, small blades should be selected as much as possible and the spacing should be reduced. The length of the vertical cutter is determined according to the height of the rapeseed in different regions. After the height of the main cutter is raised from the ground, the cutting height of the separating cutter should meet the requirements of rape harvest. The schematic diagram of the separating cutter is shown in Figure 10.

**Figure 9.** Schematic diagram of blade cutting analysis.

**Figure 10.** Schematic diagram of measuring cutter.
Dong Jiandong pointed out that the transmission mode of the vertical cutter includes indirect transmission and direct transmission[39]. Indirect transmission uses the power of moving parts near the header to drive the vertical cutting blade to reciprocate through the transmission mechanism. This transmission mode is low in cost and easy to modify, but the transmission route is long and resonance is easy to occur. Direct drive uses power components such as electric motors or hydraulic motors to directly drive the vertical cutter through a transmission mechanism. This transmission mode has adjustable frequency and short transmission route, which can effectively avoid resonance. At the same time, it can be installed on both sides of the header to provide power for the double-sided vertical cutter. The design example uses direct transmission, as shown in Figure 11, using a small gear hydraulic motor to drive the cutter to work through a crank connecting rod structure.

Xu Lizhang optimized the design of the main components of the 4LYB1-2.0 rape combine harvester[40]. The separating cutter adopts the form of a double-acting blade, and uses a small blade with a light edge. The cutter power is provided by a hydraulic motor. The hydraulic motor drives two connecting rods to drive two movable blades through the crankshaft. The structure has low vibration, low noise and simple transmission. The structure of the rape header is shown in Figure 12.

Figure 11. Transmission structure

Figure 12. Structure of rape header
Li Qinglin established the kinematic model of the horizontal cutter drive mechanism and the virtual prototype model of the vertical cutter drive mechanism of the 4-LYZ rape combine[41]. The driving mechanism is shown in Figure 13. ADAMS was used to obtain the excitation force of the horizontal and vertical cutter drive mechanism to the frame during movement through simulation measurement. The simulation results show that when the cross cutter reciprocates, the load acting on the swing ring box is a simple harmonic load, and the amplitude of $F_x$ is 3200N, which is much larger than $F_y$. When the vertical cutting moves up and down, the exciting force acting on the frame of the header changes cosine. $F_y$ is much larger than $F_x$, and the amplitude of $F_y$ is 2637N. The simulation results provide a basis for the dynamic analysis of the header frame.

![Figure 13. Structure of slider-crank mechanism.](image)

In the same year, Li Qinglin used ANSYS to analyze the harmonic response of the frame of the header based on the theoretical analysis of the force of the horizontal and vertical cutter drive mechanism of the 4LY-Z rape harvester[42]. The vibration of the header frame when the 4LY-Z rape harvester works in the field is simulated. It can be seen from the results that the vibration of the header frame is increased due to the addition of the vertical cutter. The structural change has little effect on the vibration of the header, but the addition of the vertical cutter drive mechanism aggravates the vibration of the header frame. The simulation results are consistent with the vibration produced by the harvester working in the field. This result provides a theoretical basis for reducing vibration and lightweight design of the header frame.

Gao Zhipeng analyzed the modal characteristics of the header frame with the electric drive double vertical cutter with single-action blade[43]. The analysis shows that the vertical cutter support beams at both ends of the header swing from side to side, which can easily cause loss of header during harvest. Through the study of the relationship between the vibration of the header of the rape combine harvester and the loss of the header. It is found that the loss rate of the separating cutter increases with the increase of the amplitude of the lateral vibration displacement, and finally stabilizes around 1.96%. Asymmetrical improvements were made to the frame of the header. In order to reduce the vibration amplitude of the vertical cutter, strengthened supports were installed to increase its structural rigidity. Vibration tests under no-load conditions were carried out both on the header before improvement and after improvement. The test results show that the overall vibration acceleration root mean square value of the improved header and the transverse vibration amplitude in the middle of the vertical cutter are significantly reduced. Field test results showed that after the addition of reinforced supports, the loss rate of seperating cutters decreased by 87-93%, and the loss rate of headers decreased by 34-58%.

Yang Yang designed a split cutter using a flat five-bar mechanism[44]. The vertical cutter is driven by the machine's own power source to reciprocate, and its movement diagram is shown in Figure 14. The driving rod and the connecting rod form an eccentric connecting rod mechanism through the crank, so that the connecting rod makes a circular motion around the driving rod with the crank length as the radius. The connecting rod drives the central rotating rod hinged on the longitudinal cutter holder to swing at a certain angle, and the central rotating rod drives the rocker
hinged at the other end. The rocker is connected with the hinged plate of the moving blade, and along with the movement of the rocker, the vertical cutter is reciprocated cutting through the transmission of the hinged plate. Through the modal analysis of the header frame, it is solved that the crank excitation frequency is not within the first ten-order natural frequency range of the header frame. Therefore, the mechanism does not undergo mechanical resonance.

Guan Zhuohuai designed an electrically driven two-way separating cutter, which is installed on the side panel of the header[45]. The motor drives two eccentric wheels through a pair of transmission gears. A crank is installed on the eccentric wheel, and the crank drives the blade to reciprocate up and down. As shown in Figure 15. The displacement, velocity and acceleration curves of the two blades are the same, but the phase difference is \( \pi \). The acceleration inertia force of the two blades is offset, which reduces the vibration of the header. According to the movement characteristics of the symmetric double eccentric wheel, the main parameters of the mechanism are determined, and the moving blade cutting motion trajectory equation is established. The cutting effect under different cutting speed ratios is simulated. Taking the minimum sum of uncut rate and repeated cutting rate as the requirement, the calculation results show that the cutting effect is best when the cutting speed ratio is 1.1. The vibration test shows that when only the vertical cutter is working, the vibration acceleration of the header is 0.11g, which is 11% of the vibration acceleration of the transverse main cutter. Field test results show that the average loss rate of the separating cutter is 1.03%.
Shao Bin replaced the side splitter of the combine harvester with a cutting device, which solved the problem of losses caused by pulling branches during the rape harvesting process[46]. The transmission part is shown in Figure 16. The driving gear and the header drive gear are integrated. It drives the blade drive gear to rotate through the chain and the intermediate transmission wheel. The shaft and bearing on the blade drive gear rotate while driving the blade through the connecting rod for linear reciprocating motion. In this driving mode, the blade will be subjected to horizontal force when it reciprocates in the vertical direction. In addition, there are gaps between the blade, the blade press and the blade guard, which will inevitably cause the vibration of the vertical cutter and increase the loss and failure rate of header. In order to solve the vibration problem caused by the lateral force, the transmission part of the seperating cutter has been improved, as shown in Figure 17. A slider and track are installed at the connecting rod. The slide rail mechanism is used to offset the lateral force and reduce the instability of the blade during linear movement. The improved separating cutter reduces the load of the header transmission system while ensuring the original operation effect, and improves the life and operation efficiency of the header.

![Figure 16. Diagram of seperating cutter.](image16)

![Figure 17. Diagram of improved structure of seperating cutter.](image17)

Chen Cuiying used Adams to draw the trajectory of the cutter blade, and obtained the uncut area distribution, as shown in Figure 18(a)[47]. Through analysis, it is concluded that the area a of the uncut area increases as the advancement distance of the machine increases within the time the cutter completes one stroke. Under the condition of a certain machine forward speed, the area of uncut area decreases with the increase of crank speed nc. But when the speed reaches a certain value, the area of the uncut area gradually changes slowly and smoothly, as shown in Figure 18(b). This research provides a basis for future follow-up control research on seperating cutters.
In order to enable the cutting frequency of the separating cutter to be adjusted in real time with the forward speed of the harvester, so as to reduce the loss caused by missed cutting and recutting, Chai Xiaoyu designed a follow-up adjustment device for the cutting frequency of the rape header separating cutter[48]. The left and right vertical cutters of the header are driven by a stepping motor and a crank slider mechanism. The cutting frequency control system of the separating cutter is composed of a machine forward speed sensor, a PLC controller, a stepping motor and a vertical cutter, as shown in Figure 19. The PLC control program includes three subroutines: reading the machine's forward speed, calculating the cutting frequency and driving the stepping motor. It can accurately adjust the cutting frequency to the ideal value when the harvester is operating at a fluctuating speed in the field. Field test results show that after turning on the frequency control device, the total loss of the header dropped by 36.15%~41.16%, and the loss of the separating cutter dropped by 40.84%~48.20%. It can be seen that the follow-up adjustment device can significantly reduce the loss of the separating cutter, thereby reducing the loss of the header.

2.3. Research related to screw conveyor
Rape stalks are tall and sturdy, which is easy to cause the header conveyor to be twisted and blocked during the conveying process. At the same time, the field harvesting environment is complex and changeable. During the operation of rape combined harvesting, the feed rate fluctuates due to the fluctuation of the forward speed, and it will also cause blockage of the header screw conveyor.

Li Haitong designed a compound screw conveyor whose structure is shown in Figure 20[49]. The primary cylinder structure is shown in Figure 21. Cutters are installed between the pushing blades of the cylinder according to a certain rule. When the stalks are pushed to the extend-retract fingers, the cutters cooperate with the guide blades of the top cover to initially cut off and thresh the rape stalks. During the transportation of rape stalks, rape pods with high maturity are initially detached. The grains
fall on the header, and together with light debris are collected by the horizontal screw conveyor installed under the primary cylinder to reduce header loss during harvest.

Figure 20. Structure sketch of the compound screw conveyor.

1—the primary cylinder; 2—guiding cover; 3—sieve; 4—horizontal conveyor; 5—hoisting conveyor

Figure 21. Structure sketch of the primary cylinder.

1—cylinder; 2—the axial pushing blade; 3—cutter; 4—extend-retract finger; 5—the reverse push blades

Li Haitong also designed an adaptive adjustment mechanism for the screw conveyor gap of the header in order to solve the blockage problem due to the fluctuation of the feeding amount during the rape combined harvest[50]. Its structure is shown in Figure 22. The pre-tension spring passes through the support plate and contacts the bottom of the slider to provide a certain pre-tension force. In the working process, the screw conveyor receives the reaction force of the material in the process of conveying the material. When the feeding amount increases to a certain extent, the supporting force of the support plate returns to zero, and the slider moves upward under the action of the pre-tightening force and the material reaction force, increasing the gap between the cylinder and the bottom plate. The conveying capacity of the screw conveyor increases with the increase of the gap.
2.4. Research related to overall configuration of rape header

At this stage, the popularity of rapeseed harvesting in my country is relatively low, and the folks still widely use rice harvesting headers derived from rice and wheat combine harvesters. Types include:

(1) The rice-wheat header is equipped with a vertical separating cutter. Its main feature is to install the rear baffle on the header of the existing rice-wheat combine harvester. The separating cutter of rape is driven by the main cutter through the swing ring.

(2) Docking header with separating cutter. It is combined by the method of connecting the rape header and the rice-wheat header, which has the characteristics of rapid connection[51].

The plants and grains of rape are quite different from those of rice and wheat. The use of modified headers for harvesting operations will inevitably have certain limitations. Designing special headers for rapeseed crops based on the characteristics of rapeseed is the future development direction of rapeseed harvesting.

Ma Yanning pointed out that the modified rape header should meet the following three requirements:[52]:

(1) In order to make the rapeseed that burst due to the impact of the reel fall in the header, the horizontal cutter of the header and the side separating cutter should be extended forward to the front of the reel.

(2) Install the vertical cutter at the front of the left side of the horizontal cutter and the rear of the left divider obliquely. This ensures that the front and rear positions of the upper end of the vertical cutter are between the reel and the horizontal cutter, and the left and right positions are on the left outer side of the bottom plate of the header. The rapeseed cut from the inside of the vertical cutter falls into the header. The small branches that are cut off on the outside are not easy to fall down, and are strung together with the branches in the uncut area to be recycled together in the next round of harvesting.

(3) Increase the height of the header baffle, which can reduce splash loss while not hindering the lifting of the header.

Ma Lina took the header of the 4LL-1.5Y crawler rape combine harvester as the research object[53]. Respectively under three typical working conditions: only engine working, engine and working parts working at the same time, and field harvesting operation. Three measuring points were selected on the header to test the vibration of the header of the rape combine harvester. The experimental data is processed based on time domain analysis, wavelet analysis and frequency domain analysis. Research shows that the main vibration source of the header is the engine, reel and cutter, and the secondary vibration source is screw conveyor. After the crop is fed into the header, it absorbs part of the vibration, which reduces the total vibration of the reel and cutter by 23.5% and 68.7%.
respectively. The vibration signal of the header is mainly concentrated in 0~125Hz, and the frequency of each excitation force on the header of the rape combine is mainly low frequency. In order to avoid machine resonance, the natural frequency of the header should be considered when designing the header structure.

Zareei adopted Taguchi's method to analyze the adjustable factors affecting the loss of the Clas 510 header[54]. Using the L18 orthogonal matrix, a total of 54 sets of experiments were arranged, and the factor that has the greatest influence on the loss of the header is the machine forward speed. At the same time, the best combination of working parameters to minimize the loss of the header is that the forward speed is 2.5km/h, the reel speed is 3 km/h, the stubble height is 30 cm, the horizontal distance of the cutter is 10 cm, and the vertical distance of the cutter is 5 cm.

Zha Yuehua proposed a telescopic header[55]. The main cutting device is connected to the left and right side plates of the header frame through the cutter beam fixing seat. When the header is in the forward position, it is used to harvest rape, and a vertical separating cutter is installed on the header to make the cut rape stalks, pods, and seeds all fall into the header, as shown in Figure 23. When the header is in the retracted position, it is used to harvest rice and wheat. Remove the vertical cutter and install the crop divider, as shown in Figure 24.

![Figure 23. The state of the header when harvesting rapeseed.](image)

![Figure 24. The structure of the new eccentric reel.](image)
Fang Daxing analyzed the overall structural mechanics and vibration characteristics of the rape header[56]. The structure is optimized by adding supports and stiffeners. The improved header structure is shown in Figure 25. The finite element analysis was performed on the rape header before optimization and the rape header after optimization. Vibration tests were carried out in the field. The results show that the first-order modal frequency of the optimized header can effectively avoid the excitation frequency range of the cutter, the driving wheel of the chain conveyor and the threshing cylinder, which reduces the vibration of the header.

Lopes used the linear quadratic Gaussian and loop transfer recovery methods to design the height control system of the combine harvester[57].

After Hobson identified the cause of rape seed loss through experiments, he designed a new type of cutting table with a wide width and a conveyor belt behind the cutter[37], as shown in Figure 26. Through the comparison test with the standard rape header, it can be seen that the wide header is beneficial to reduce the loss of shattering. And the conveyor belt helps cut crops to flow into the screw conveyor. The loss of the main cutter of the modified header is 1/2 less than that of the standard header.
Ji Muye designed a stripping header for rape harvester[58], the structure of which is shown in Figure 27. During the stripping process, the stripping element is inserted into the rape silique layer that has entered the header. The direction of rotation of the stripping drum is opposite to the machine forward direction. The combing element and the rapeseed produce relative movement, combing the silique layer of rapeseed from bottom to top and throwing the seeds backwards. This can reduce the loss of fried pods during the rape harvest.

Tang Shengping developed a rape grooming device[59]. He designed the overall structure of the stripping drum with cam slide form, and its structure is shown in Figure 28. The arrangement of the fingers is that the single finger rollers are evenly arranged, and the adjacent finger rollers are arranged staggered, which can increase the area covered by the fingers on the rape. Considering the problem that the rape is inclined to the outside of the header under the action of the stripping drum, the structural parameters of the reel, the relative position of the stripping drum and the motion parameters are analyzed and designed to meet the requirement that the reel transport time is longer than the stripping drum combing time. The structure of the reel and header is shown in Figure 29.
Pan Haibing designed a longitudinal positive pressure airflow collection device[60]. It is composed of a lateral main pipe and several branch monomers. The monomer is composed of a longitudinal gas pipe, a vertical gas pipe and a nozzle, as shown in Figure 30. The device is mounted on the front of the header in a hanging mode. When the collecting device is working, the high-speed airflow is ejected from the monomer nozzle, and the airflow from the adjacent monomers is collected to form a longitudinal high-speed airflow layer backward and upward. The grains in the collection range of monomer can enter the header and be effectively collected under the action of positive pressure and high-speed airflow.

Huang Xiaomao proposed an on-line collection method and device for falling grains from the header based on lateral positive pressure airflow[61]. Its structure is shown in Figure 31, and the cooperation between the device and the header is shown in Figure 32. When the device is working, the high-speed airflow is blown out by each nozzle, and a high-speed airflow layer is generated in front of the nozzle. When the machine is working in rows, there is a row of rape plants between every two collection tanks. During harvesting, splashed grains enter the collection area. Through the action of the airflow, the grains will generate a certain lateral velocity, and then fall into the collecting trough and slide into the header.
3. Conclusion

Scholars from all over the world have carried out relevant research on the structure, vibration and follow-up control of the rape harvester header. For the purpose of reducing the loss of the harvesting header, the rape harvesting header has been optimized. The research results have important guiding significance for the improvement and design of future products, and will help promote the mechanization of rape harvesting. However, the problems addressed by these studies are relatively single and at the same time not deep enough. There is still much room for improvement in the rape header.

3.1. Design of vertical cutters with different structure

Separating cutter is a special structure of the rape header. At present, the structure of the separating cutter is relatively simple, generally using reciprocating single-acting blade or double-acting blade, and driven by the machine's own power or a separate motor or hydraulic motor. The reciprocating cutter has a perfect structure and reliable work. It is widely used as the main cutter of a rice-wheat combine harvester. However, the installation position and working conditions of the separating cutter are different from those of the main cutter, which will bring longitudinal excitation force to the header. At the same time, it also receives lateral force from the main cutter and other working parts, which in turn causes lateral vibration and increases header loss.
Folks have used a double disc cutter as the separating cutter of the rape header. The results of the operation have proved that this type of cutter has high cutting efficiency and low vibration, but it is easy to be entangled and blocked, and there is a risk of failure. Based on similar cases and referring to the research status of the main cutter, various types of crop cutters, such as multi-disc cutters and circular chain cutters, which can be developed in the future. This type of separating cutter does not need to be driven by a crank slider mechanism, and can be powered directly by the working parts of the header, thereby reducing vibration and loss. At the same time, there is no need to install a motor or hydraulic motor on the header, which can reduce the cost and weight of the header, and improve the working reliability of the whole machine.

3.2. Further research on follow-up control
At present, there have been certain research results on the follow-up control of each working part of the header, but its realized function is relatively single, and there are other aspects worthy of in-depth study.

Taking the separating cutter as an example, the currently widely used separating cutter is vertically fixed on one side or both sides of the rape header, and is raised or lowered together with the header. The height of the header is adjusted by rotating around the center, which determines that the angle between the separating cutter and the ground will change in real time during the lifting process. The existence of the inclination angle causes the entangled branches to be cut successively during the working process, which reduces the division effect and increases the loss of the separating cutter. The fixed connection between the separating cutter and the header can be changed to an active connection. The angle of the vertical cutter is adjusted in real time during the lifting process of the header through the sensor and the motor to keep it perpendicular to the ground, which can ensure cutting consistency.

3.3. Analysis of the overall vibration of the header
The rape header is mainly composed of a main cutter, a separating cutter, a reel, a screw conveyor and related transmission devices. During the working process of the header, the sources of vibration are many. At this stage, the analysis of the vibration of the rape header is relatively simple, only considering the impact of the excitation force generated by individual mechanisms on the header. In actual operation, each mechanism will also be affected by each other's excitation load, and the vibration of the header is a complicated and mutual result.

Therefore, it is necessary to deeply understand the working mechanism of rape header. Establish a more accurate header model, analyze the excitation loads of different directions and different magnitudes received by each mechanism, so as to obtain the true response of each part. Optimize the configuration relationship of the cutter, reel, pusher and transmission part based on the actual situation. At the same time, design and strengthen the header frame more reasonably, reduce header vibration and reduce header loss.

3.4. Mechanical analysis of entwined branches of rape
The cutting effect is not only related to the cutter, but also closely related to the object to be cut. At this stage, there have been very complete studies on the flexural and shearing characteristics of various crop stems, and the main cutter can often bring very good operating results. However, the intertwining of rapeseed branches is a relatively complex structure, which is difficult to quantify and requires extensive investigation in the field. It is necessary to use computer technology to simulate and calculate a variety of typical models, and then analyze and summarize the cutting characteristics of this staggered structure, which provides a theoretical basis for the design of the grain cutter and reel.

3.5. Combination of agricultural machinery and agronomy
Rapeseed plants have special characteristics. During the harvesting process, a separating cutter is required to divide the rapeseed field into harvested and unharvested areas. This process is prone to loss of pod burst. In order to ensure yield, crops are often planted intensively. In recent years, the rise of
the combination of agricultural machinery and agronomy has brought new ideas to the planting of crops.

The separating cutter and the reel in contact with the rape branches will inevitably cause the loss of burst pods. The combination of agricultural machinery and agronomy can be used to avoid this kind of loss. On the one hand, the width of the header of the rape harvester can be widened. On the other hand, the planting distribution of rape can imitate the planting pattern of wide and narrow rows of rice. For each row of rapeseed, reduce the spacing between rapeseeds appropriately, that is, plant more rapeseeds in each row. This can supplement the rapeseed planting density. At the same time, a certain distance is created between every certain number of rows of rapeseed to form a partition area, which ensures that the branches of rapeseed on both sides will not be entangled. And the distance between adjacent partitions should be equal to the width of the rape header. Under this kind of planting mode, by using a rape harvester that matches the width of the header, the cropping devices on both sides of the header are running in the partition area and will not contact the entangled rape branches. Which can avoid a large number of burst pod loss.

For reasons of economic efficiency, China’s current rapeseed cultivation is decreasing year by year, and the penetration rate of mechanized rapeseed production is relatively poor. This is a fact but also an opportunity. The mechanization of agriculture in China is in a stage of accelerated development. The continuous introduction of new technologies and the expansion of agricultural operations are stimulating the process of agricultural mechanization. It is necessary to take this opportunity to conduct in-depth research and innovation on the rape combine harvester to make it more targeted and have better operating results. In turn, it will reduce the cost for farmers to plant rapeseed, improve the efficiency of rapeseed production, and attract more farmers to invest in rapeseed cultivation.

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