Design and Analysis of Film-Covering Direct Seeding Machine in Paddy Field

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Abstract. To realize the mechanization of film-covering direct seeding in paddy field, this paper analyzes the agronomic requirements of film-covering direct seeding of rice and the characteristics of paddy field operating conditions, and designs the overall structure of film-covering direct seeding machine by referring to the mechanical properties of degradable plastic film and paddy field working conditions. This machine adopts suspension structure and is powered by the handpiece of high speed rice transplanter. In the process of design, the resistance should be reduced as far as possible on the premise of film laying, so that the structure can be light and simplified to ensure the excellent trafficability of machines and tools in the paddy field. The power parameters and other main parameters of the direct seeding machine are determined. The stress of the designed machine during working is analyzed, which provides reference and basis for the subsequent research on the direct seeding mulch applicator in paddy field.

Keywords: Paddy Field Direct Seeding Machine, Mechanical Analysis, Structural Design

1. Introduction
In recent years, great changes have taken place in rice planting conditions. With the acceleration of urbanization, the rural labor force has been transferred, and there is an increasing shortage and aging of labor force in agricultural production. With the continuous advancement of agricultural modernization, the mechanization productivity of rice planting has been greatly improved, but the mechanization rate is relatively low. By 2016, the mechanization rate of rice planting was only 44.5%, which was far lower than the rice cultivation rate of 99.3% and harvest rate of 87.1% (Luo Xiwen, 2019). Therefore, developing the rice planting technology that is easy to realize mechanized production as well as corresponding supporting machines and tools are of great significance for adapting to the current situation of rice production and realizing the full mechanization of rice production [1-3].

Direct seeding technology is one of the effective ways to improve the mechanization degree of rice planting, which has more simple and easy operation and lower machinery investment cost compared
with the method of rice transplanting. In Europe, America and other developed countries, rice planting is dominated by mechanical direct seeding. Particularly, the mechanical direct seeding is the dominant and only way to plant rice in the United States, which helps realize the whole-process mechanized production of high-quality rice. However in China, mechanical transplanting is the main mode of rice planting, direct-seeding covers only 30% of the rice planting area, and the mechanization degree is low, in fact artificial sowing is still in the dominant position. Due to the problems of prolongation of low temperature growth period, vulnerability to drought, and serious weed damage, direct seeding of rice is rarely applied in rice production in East Asia and Southeast Asia areas such as China. The mulching technology of rice cultivation has obvious water saving effect and temperature increasing effect, and can effectively inhibit the growth of weeds in the field and reduce the use of herbicides. Mulching cultivation of rice can also promote rice growth and increase yield. In the early stage of rice growth, it makes rice reach the tillering peak earlier, and the tillering number is 24% and 35% more than that of mechanical transplanting and common direct seeding (Song Yuqiu, 2017). The average yield of rice by mulching cultivation can be increased by 12% (Liu, 2003). Therefore, the research on the combination of direct seeding and mulching seeding in paddy field is of great significance for improving the productivity of rice mechanization, reducing farmers’ labor intensity, reducing the use of pesticides and fertilizers, producing green and healthy organic rice, increasing rice yield and increasing farmers' income [4-7].

2. Working Principle of Film-Covering Direct Seeding Machine in Paddy Field
During operation in paddy fields, the working condition of film-covering direct-seeding machine is relatively complex, the force of mud applied on the machine changes greatly, and the machine needs to turn and cross field ridge, so the working performance of the machine is affected by many uncontrollable factors. Therefore, on the basis of meeting the agronomic requirements of mulching planting of rice, the structure of the machine should be simplified as much as possible so as to improve the working reliability of the machines and tools. The film-covering direct seeding machine is mainly composed of film hanging device, film pressing roller, edge pressing wheel and frame, and is connected with the suspension system of the rice transplanter, as shown in Figure 1.

![Figure 1. Mechanism of film-covering direct seeding machine in paddy fields](image)

Install the film roll on the film hanging device. When the machine is laying the film, pull out the film and lay it under the film pressing roller and the edge pressing wheel. As the machine moves forward, the film is continuously pulled out, covering the soil surface, and pressed tight, then the edge pressing roller presses both sides of the film into the soil to complete the film-covering direct seeding operation [8-10].

3. Selection of Supporting Power for Film-Covering Direct Seeding Machine
Due to agronomic requirements of rice planting, characteristics of farmland soil and geographical environment, paddy fields are often irregular in shape and size, with large differences in soil properties,
uneven height of mud and relative horizontal height difference between plots. Therefore, the handpieces of high-speed transplanters with light weight, flexible turning, excellent trafficability are often selected as power source, such as Kubaotian 2ZGQ-6G1 (SPV-6C) transplanter, Yangma VP6D (2ZGQ-6D) high-speed riding transplanter. Remove the planting part and install to the film-covering direct seeding machine studied in this paper [11-12].

This kind of high-speed rice transplanter has light body, narrow tire, consistent front and rear wheel pitch, and causes little damage to the mud surface when driving in the field, which can better ensure there are no gullies on the mud surface under the film and reduce the hanging of rice seeds. Large ground clearance and four-wheel drive enhance the trafficability of the machine in the muddy soil and guarantee high working speed. Taking Kubotian 2ZGQ-6G1 (SPV-6C) transplanter as an example, the dynamic parameters are shown in Table 1.

Table 1. Kubota 2ZGQ-6G1 (SPV-6C) rice transplanter parameters

| Main Technical Parameter | Value          |
|--------------------------|----------------|
| Driving type             | Four-wheel drive|
| Mass (kg)                | 715            |
| Rated power (kW)         | 9.2            |
| Front wheel diameter×width (mm) | Ø650×95 |
| Rear wheel diameter×width (mm) | Ø 950×50 |
| Wheel Base Length (mm)   | 1200           |
| Working speed (km/h)     | 0 ~ 5.83       |

4. Structural Design and Stress Analysis of the Machine

According to the technical parameters such as the Wheel Base Length of the high speed rice transplanter and the limit working position of the suspension device, the length, width and height of the machine are designed to be 864mm, 1879mm and 658mm, respectively. Films with row spacing of 1.3m~1.7m and the diameter not exceeding 500mm can be laid. The overall structure of the direct seeding machine is shown in Figure 2. The two ends of the film hanging device are installed on both sides of the frame by hinge supports, and one end of the film hanging device is arranged in a form of easy disassembly for the portable installation of film rolls. The film roller is hinged to the two sides of the plate through the connecting arm. For both sides of the machine, one edge pressing wheel fixed on the side plate by a axle.

Figure 2. Film-covering direct seeding machine for rice planting

When the handpiece of the high-speed rice transplanter carrying the film-covering direct seeding machine is working, the whole process can be regarded as uniform linear motion except for the short start-up acceleration section. Therefore, the static equilibrium method is adopted to analyze the force of the machine when it is working. The stress diagram is shown in Figure 1-3. Where, FQx and FQy
are the horizontal and vertical components of the traction force of the tractor suspension device on the direct seeding machine respectively, and the resultant force direction is the connecting direction of the tractor suspension device and the direct seeding machine suspension point. \( W \) is the weight of the machine (including the weight of the film roll and the film press roller). The film pressing roller is subject to the supporting force \( N_1 \) of the mud surface and the rolling friction \( F_f \) between the plastic film and the film pressing roller, which is very small and can be ignored in the balance analysis of the whole machine. The edge pressing wheel is actually a driven wheel, which produces rotation by friction with the soil and the film and pushes the edge of both sides of the film into the soil. Therefore, the force on any contacting point between the edge pressing wheel and the soil can be divided into tangential stress \( \tau(\theta) \) and legal stress \( \delta(\theta) \). Moreover, tangential stress \( \tau(\theta) \) can also be denoted as rolling friction between the edge pressing wheel and soil, which is very small and ignored in the balance analysis of the whole machine. The resistance of the edge pressing wheel when it enters in soil and advances forward is related to the maximum entry angle \( \theta_0 \).

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\begin{align*}
F_{Qx} + 2br \int_{0}^{\theta_0} \delta(\theta) \sin \theta d\theta &= 0 \\
F_{Qy} - W + N_1 + 2br \int_{0}^{\theta_0} \delta(\theta) \cos \theta d\theta &= 0 \\
F_{Qx} \cdot L_3 + N_1 \cdot L_1 - W \cdot L_2 - F_{Qx} \cdot L_4 &= 0
\end{align*}
\]

Figure 3. Stress of film-covering direct seeding machine

In an ideal state, according to the equilibrium condition of the plane convergence force system: \( \Sigma F_x = 0, \Sigma F_y = 0 \). Equilibrium condition for a plane couple of forces: \( \Sigma M_O = 0 \), the balance equation of the machine model is obtained.

Where:
- \( F_{Qx}, F_{Qy} \)—The horizontal and vertical components of the driving force, N;
- \( b \)—Width of edge pressing wheel, mm;
- \( r \)—Radius of edge pressing wheel, mm;
- \( \theta_0 \)—Maximum entry angle, (°);
- \( \theta \)—The angle between the line going through any earth contact point of edge pressing wheel and O point and the vertical direction, (°);
5. Conclusions
This paper mainly designs the overall structure of the film-covering direct seeding machine: By referring to the mechanical standards of film-covering direct seeding machine, its main operating performance indexes are determined. According to the agronomic requirements of mulching cultivation of rice and the characteristics of paddy field operation, the overall structure of the direct seeding machine is designed, and the handpiece of the high-speed transplanter is selected as the power element. The main structural parameters of the whole machine are determined, and the mechanical analysis of the whole machine is carried out, which provides the foundation for the structural design of other key components.

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