

Original Paper

Research Status of High Clearance Sprayer and Its Steering System at Home and Abroad

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Abstract

This paper introduces the representative domestic and foreign high-gap sprayer models, and expounds the current research status of the steering system of the high-gap sprayer, which provides reference for the further development of high-gap sprayer and other products in domestic enterprises and universities.

Keywords

high clearance sprayer; high clearance sprayer steering system, four-wheel steering, plant protection machinery

1. Introduction

As a superpower with a population of more than 1.4 billion, the output and quality of food has always been a priority for China's people. As one of the most important food crops in China, rice has a planting history of more than 7000 years. According to data from the National Bureau of Statistics (NBS), from 2014 to 2020, the total sown area of rice in China will remain above 30 million hectares, and the rice output will fluctuate slightly around 200 million tons. Large area of rice planting, plant protection, such as harvest work requires a lot of manpower material resources to participate in, with the development of urbanization, the rural population transfer to non-agricultural industries, to the town gathered momentum, farmed, reduce is bound to threaten China's grain planting area and yield, it is the demand for agricultural mechanization in our country is more urgent.

In recent years, domestic and by introducing the research highland gap spray machine, make the efficiency of the plant protection has improved, but the foreign high gap sprayer is given priority to with large and expensive, and relatively small and fragmented plots in most areas of China, so the imported large sprayer is difficult to popularize, the research of high gap on the mechanical properties

of the sprayer and the efficiency is relatively developed countries gap is larger, The walking system, spraying system and control system of the highland gap sprayer need further research and development.

2. Research Status of High Clearance Sprayer at Home and Abroad

2.1 Foreign Research Status

Foreign research on high-gap sprayers started earlier, represented by developed countries such as Europe and the United States. Foreign plant protection machinery is mainly large and medium-sized sprayers, which have a high level of intelligent and automatic walking and precision spraying. The walking system is widely equipped with obstacle detection system and GPS positioning system. Spray system is widely equipped with variable spray system, real-time mixing system, liquid recovery system and automatic leveling system of spray rod. With the continuous development of modern science and technology, plant protection machinery and its spray technology in foreign countries are developing in the direction of intelligence, unmanned and integration.

The R4030XN self-propelled sprayer produced by John Deere (2021) in the United States is shown in Figure 1. The R4030 self-propelled sprayer is equipped with a Powertech PSS 9.0-litre engine with two turbochargers -- one variable geometry turbocharger (VGT) and one fixed geometry turbocharger, which greatly improves engine torque and response to handle harsh field conditions. The chassis is equipped with two kinds of suspension systems, one is the air suspension with two independent wheels, the other is the automatic air spring leveling system, which greatly improves the driver's comfort. The spray width of the sprayer is up to 36 meters, with a double swing rod suspension, the spray rod height is stable, and can ensure that the spray height is always higher than the crop height. Spray rod can also be equipped with air cleaning equipment, the use of air circulation in the process of changing the liquid to achieve the effect of cleaning spray rod. The walking system of the sprayer can realize the functions of automatic driving and automatic navigation, and the spray system can realize the variable spray function, which ensures the intelligent and accurate spray. Due to the heavy chassis, large volume, it is difficult to adapt to most of the domestic paddy environment.

The Tecnomas Laser self-propelled sprayer (2021) produced by the French Tecnomas Company is shown in Figure 2. The Tecnomas Laser is powered by a 240-horsepower Deutz six-cylinder engine, with a maximum chamber capacity of 5,200 litres and a spray rod length of up to 42 metres. Laser uses a rugged and comfortable welded rectangular box chassis with Axair suspension, hydraulic wheelbase adjustment, four wheel drive, two wheel steering and four wheel steering modes, and crane handling with rear-axle tilt correction. The sprayer is equipped with GPS positioning system, which can realize the functions of automatic driving, automatic spraying rod division and automatic tracking. However, it is only suitable for dry field, field and other operating environments, and it is difficult to adapt to the operating environment of paddy field.



Figure 1. John Deere R4030XN



Figure 2. Tecnomas Laser

The JKB22C self-propelled sprayer produced by Dongfeng Iseki Company in Japan is shown in Figure 3. Dongfeng JKB22C self-propelled sprayer is equipped with E3112-J06 vertical water-cooled 4-stroke 3-cylinder diesel engine, rated power 16.3KW, four-wheel drive, four-wheel steering, small steering radius, medicine box capacity of 500L, spray rod spray width of 11.5m, spray rod height of 660mm~1660mm adjustable, at the same time can also be installed fertilizer dispenser mechanism, For fertilizer spraying, the overall weight of the sprayer is light and the wheel width is narrow, which can reduce crop damage and deep paddy field. However, the driving system adopts mechanical transmission mode, which may cause bending of the walking mechanism and damage of the transmission structure under complex working conditions such as paddy field, affecting the walking of the sprayer. At the same time, the sprayer needs to be driven by a human, and there are risks such as high labor intensity and health of the drivers.

The 3WP-600CN self-propelled spray rod sprayer (2020) produced by Japan Iytoon Maruyama Company is shown in Figure 4. It is equipped with water-cooled 4-stroke 3-cylinder vertical diesel engine, fuel saving and sufficient power, rated power 18.1KW, four-wheel drive, four-wheel steering, small steering radius, effectively reduce the crop damage when steering, 600L medicine box capacity, spray rod spray can reach 20M, The spray rod arm can be electrically telescopic, hydraulic opening and closing as well as hydraulic up and down adjustment, which improves the efficiency of plant protection. However, the driving system also adopts mechanical transmission mode, which also requires human driving. It needs to be improved in the working conditions of complex paddy fields and drug mist spraying.



Figure 3. Dongfeng Iseki JKB22C



Figure 4. Eifeng Maruyama 3WP-600CN

2.2 Domestic Research Status

Domestic research on high gap of the sprayer starts late, plant protection apparatus and drug-delivery technology relative to Europe and the United States and other developed countries have a larger gap, the founding of the early prevention and control of domestic spraying mainly manual mechanical, to the ninety s of the 20th century domestic agricultural scientific and technological personnel, scientific research institutes, and agricultural machinery manufacturers began to motor plant protection machinery research and development, made some research results, In the actual agricultural product plant protection has also been promoted and applied to a certain extent, but the plant protection machinery is relatively single type and low efficiency, unable to meet the needs of different crops, different diseases and insect pest control. Meanwhile, the spraying parts are relatively backward, the effective utilization rate of pesticides is low, the waste is large, and the loss is serious. In recent years, domestic plant protection machinery enterprises have actively responded to the call of the state and continuously launched sprayers suitable for China's farmland plant protection.

The APOS ZP9500H self-propelled high-clearance plant protection machine produced by Levo Heavy Industry is shown in Figure 5 (2021). The walking system of APOS ZP9500H self-propelled high-clearance plant protection machine is four-wheel drive and four-wheel steering. The steering radius is small and the four wheels are the same, which can effectively reduce the damage rate of crops. At the same time, the front and rear differential locks can effectively prevent the spray machine from slipping and enhance the passing performance of the spray machine in complex paddy fields. The cab adopts unique wind guide technology, which can effectively prevent the liquid medicine from entering the cab and reduce the harm of liquid medicine to plant protection personnel. At the same time, it is loaded with 20L clean water tank, which can clean the residual liquid medicine in the cab, greatly improving the working environment of plant protection personnel. Spraying system adopts high pressure spray technology and the drift technology, so uniform and effective solution to cover on the crops, reduce waste, at the same time the water filter, water filter, water filter, nozzle level 4 filtration system, effectively avoid systems congestion, prolong the service life of spray system, also equipped with intelligent spraying system, can make the liquid medicine spraying is more uniform, precise, The utilization rate of pesticide was improved greatly. The sprinkler head adopts anti-drip technology, which effectively avoids the contamination of the soil caused by the leakage of liquid medicine. The water absorption system of the sprayer is equipped with anti-backflow device, which can effectively prevent the pesticide leakage of the water absorption device and protect the water source. Adopt double mixing mechanism to make the mixture more rapid and even. But the drive system also uses mechanical transmission, which also requires a human driver.

3WSH-1000 self-propelled high-clearance plant protection machine (2020) produced by Shandong Yongjia Power Co., Ltd., is shown in Figure 6. Yongjia 3WSH-1000 self-propelled high-clearance plant protection machine is equipped with 4-stroke air-cooled gasoline engine, adopting four-wheel drive and four-wheel steering structure, with small turning radius, light weight of the whole machine, only 800kg,

strong field passing ability, 400L capacity of medicine box, adopting jet mixing method, good mixing effect of liquid medicine, spray rod length of 8m, The height can be adjusted from 0.5m to 1.5m, which is suitable for comprehensive control of dwarf crops at seedling and growth stage. The driving system also adopts mechanical transmission mechanism, and the strength of the walking structure remains to be tested.



Figure 5. REVO APOS ZP9500H



Figure 6. Never better 3WSH-1000

Dongfanhong 3WX-3000HS self-propelled highland clearance plant protection machine (2021) produced by Beijing Zhongnong Fengmao Plant Protection Machinery Co., Ltd., is shown in Figure 7. Dongfanhong 3WX-3000HS self-propelled high-clearance plant protection machine adopts a combination of mechanical and hydraulic drive, which greatly improves the climbing ability of the sprayer. The drive system can realize the switch between rear-wheel drive and four-wheel drive. At the same time, it is equipped with mechanical differential lock, which can effectively prevent the chassis of the sprayer from slipping. The sprayer has strong applicable performance, and can be used for plant protection of rice, cotton, wheat and other crops in upland water field, as well as for plant protection of maize and other high-stalk crops in the early stage. Spray machine equipped with 3000L large capacity medicine box, spray rod spraying range up to 24 meters, spray system using variable spray technology, unit area dose is not affected by the change of speed, can achieve precision spray, greatly improve the crop control effect and pesticide utilization rate. But the sprayer adopts wide tire, which increases the damage rate of seedlings.

The Ward Wing Loong 3WPZ-800 self-propelled high-clearance plant protection machine produced by Jiangsu Ward Agricultural Machinery Company is shown in Figure 8. Ward Wing Loong 3WPZ-800 self-propelled high-clearance plant protection machine is equipped with high pressure common rail four-cylinder diesel engine, rated 100 horsepower, four-wheel drive, four-wheel steering, front and rear wheel rutts are the same, the minimum steering radius is 2.9m, the operation effect is better in complex paddy field, can adapt to the mud foot depth within 0.3m, matching two kinds of wheel pitch, It improves the adaptability of the sprayer to different row spacing of crops. The minimum ground clearance is 1.2m, which can adapt to tall crops. It is equipped with 800L medicine box, spray rod

spraying range can reach 14m, and fertilizer spreading device, which can be used in one machine and in two uses. However, the overall quality of the sprayer is relatively heavy, which is easy to deepen the mud feet. At the same time, the sprayer adopts wide tires, so it is necessary to improve the anti-trap ability of the sprayer during operation and increase the damage rate of seedlings.



Figure 7. Dongfanghong 3WX-3000HS



Figure 8. Ward Pterosaur 3WPZ-800

3. Research Status of Steering System of Elevated Gap Sprayer at Home and Abroad

As a typical plant protection machine in the field, the high gap sprayer's excellent steering performance is the key to its stable operation in the complex field environment. At present, the vehicle steering system mainly includes mechanical steering system, mechanical hydraulic power steering system, electric power steering system, electric power steering system and wire control steering system. Aiming at the complex operating environment of sprayer, the steering system of sprayer has been studied at home and abroad.

The research on the steering system of the high clearance sprayer started earlier and was more mature in foreign countries. In 1979, the Highland Gap Sprayer, developed by Rogator Company in the United States, could realize multi-mode four-wheel steering. Its characteristic was that it could switch freely in three modes of front-wheel deflection, all-wheel deflection and crab-wheel deflection. In 2009, Agro introduced the 3-Rex, a large sprayer with a three-axis, six-wheel steering system. Based on this chassis and steering technology, the capacity of the case can be greatly increased to a maximum of 12,000 L.

The domestic research on the steering system of the highland gap sprayer started relatively late. In order to change the current situation of the low level of agricultural mechanization in China, the state strongly supports the development of agricultural machinery and equipment. In recent years, many domestic scholars have made good research results on the steering system of sprayer. Zhai et al. (2014) improved the hydraulic steering assistance system, solved the dead zone problem in the middle position of the proportional solenoid valve by using the linear compensation method, and realized the synchronous control of the two steering wheels by using the connecting rod mechanism and the two-way hydraulic cylinder. The principle of the improved electro-hydraulic assisted steering is shown in Figure 9. Xia and Luo (2016) studied the full hydraulic steering system of the high-clearance

self-propelled sprayer, and realized the full hydraulic four-wheel steering by using the three-position four-way directional valve, which solved the problems of the traditional high-clearance sprayer's difficult steering, too large steering radius and low degree of the front and rear wheels in the same rapping. The principle of the full hydraulic steering system is shown in Figure 10.

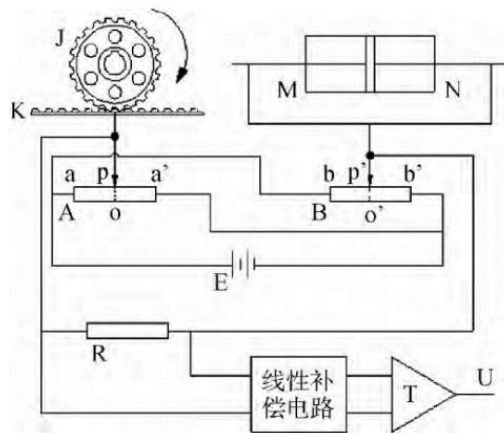


Figure 9. Schematic Diagram of Improved Electro-hydraulic Assisted Steering

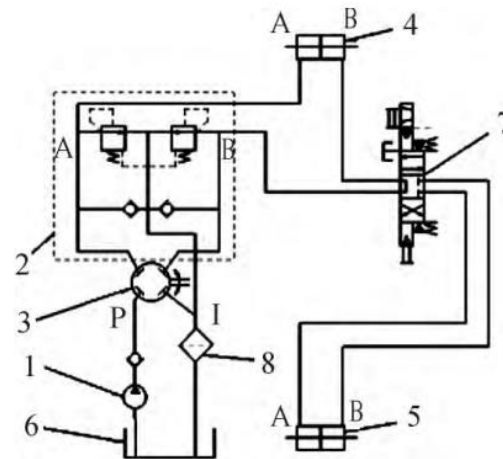


Figure 10. Full Hydraulic Steering System Schematic Diagram

Mao et al. (2012) designed the steering anti-skid control system of the hydraulic four-wheel drive high clearance sprayer, and proposed the control strategy based on the speed ratio difference, which achieved good control effect and could effectively deal with the skid problem of the high clearance plant protection machine during steering. Dou (2012) designed an adjustable wheel distance steering system of high-gap self-propelled plant protection machine, which met the requirements of different row spacing of crops and improved the adaptive performance of the plant protection machine. Li et al. (2019) designed the multi-wheel steering system of high-clearance self-propelled plant protection aircraft, which improved the maneuverability and operating efficiency of large high-clearance plant protection aircraft. Hu and Zhang (2020) designed the multi-mode hydraulic steering system of highland gap self-propelled plant protection aircraft based on PID control algorithm, which improved the maneuvering performance and operating efficiency of highland gap plant protection aircraft and reduced the damage of pressed seedlings. The principle of the multi-mode steering hydraulic system is shown in Figure 11. Chen et al. (2019) designed a set of hydraulic auxiliary driving system, which solved the problem that the seedlings were crushed and injured due to the insufficient vision of plant protection personnel during the operation of the high-gap sprayer. The principle of the hydraulic auxiliary steering system is shown in Figure 12.

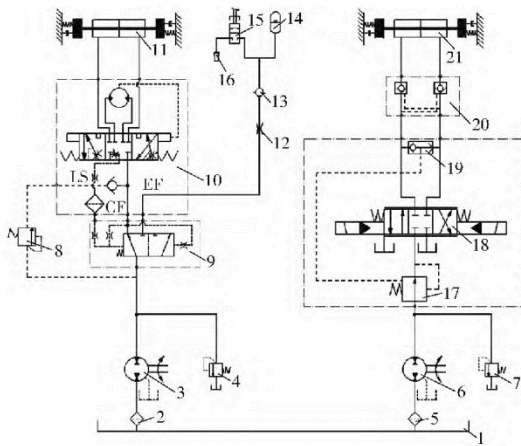


Figure 11. Schematic Diagram of Multi-mode Steering Hydraulic System

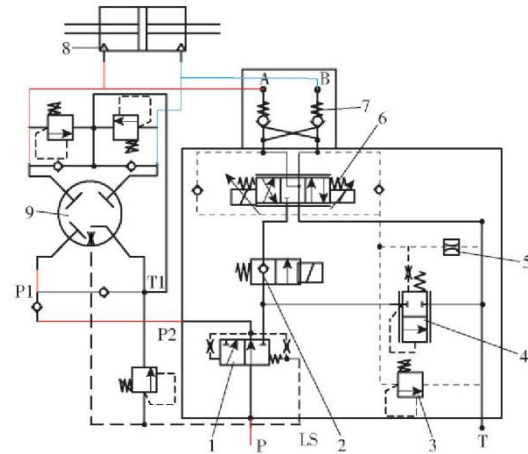


Figure 12. Schematic Diagram of Auxiliary Steering Hydraulic System

Li et al. (2018) designed a high-gap self-propelled electro-mechanical control hydraulic steering system for plant protection. With Mitsubishi PLC as the main controller, the traveling mode and steering mode of the vehicle were switched by controlling the electromagnetic directional valve, which improved the flexible performance of the high-gap plant protection machine. Tong (2014) designed a four-wheel steering control system, which can realize three steering modes of front-wheel deflection, four-wheel deflection and in-situ vehicle circumnavigation. At the same time, the wheelbase can be adjusted during the steering process of the plant protection aircraft, greatly improving the field adaptation performance of the plant protection aircraft. Zhang et al. (2015) designed the four-wheel independent steering drive control system of the self-propelled high-clearance plant protection aircraft, which improved the flexible steering performance of the high-clearance plant protection aircraft and its adaptability in the complex field operating environment, and solved the problem of high promotion and application cost of the high-clearance plant protection aircraft. Feng et al. (2016) established the hydraulic steering system model of highland clearance self-propelled plant protection aircraft, and carried out simulation analysis on the dynamic characteristics of the hydraulic steering system, providing theoretical reference for the design of the hydraulic steering system of highland clearance plant protection aircraft. Zhang (2016) designed the four-wheel steering hydraulic system of the high-clearance self-propelled platform, which improved the mobility, flexibility and mechanical performance of the high-clearance self-propelled platform. Zhang et al. (2015) established the steering control model of the independent driving system of the driving wheel of the high-clearance sprayer, and analyzed the balance of the internal and external wheel speeds when the vehicle turns, providing theoretical reference for the chassis design and the selection of important components of the sprayer. Zhang et al. (2015) designed the hydraulic steering debate domain fuzzy controller, which improved the steering control stability and accuracy in the navigation operation of agricultural wheeled vehicles. The structure of the debate domain fuzzy controller is shown in Figure 13. Lu et al. (2016) designed a two-channel PID controller

for the drive-by-wire hydraulic steering system. In view of the asymmetry of the hydraulic cylinder, the stretching and retracting movement of the piston rod is controlled in separate channels, and a good control effect has been achieved. The principle of the two-channel PID control system of the drive-by-wire hydraulic steering system is shown in Figure 14.

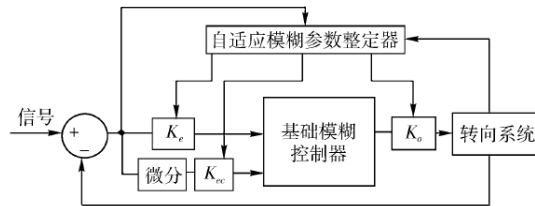


Figure 13. Debate Domain Fuzzy Controller Structure

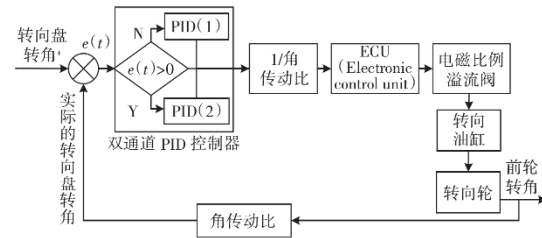


Figure 14. PID Control Schematic Diagram of Hydraulic Steering System by Wire

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