Research of key technology on self-propelled farmland levelling machine and hydraulic servo system simulation

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Abstract

According to the present situation of the farmland levelling, the equipment cost is high, maintenance is complex and its cost is high. The paper carries a research on the key technology of self-propelled farmland levelling machine. The key technology includes the levelling knife, the levelling part, the sundry separating device and the measurement and control system of the laser and inclination sensor. At the same time, the paper establishes the hydraulic servo system mathematical modal and utilizes MATLAB to analyse, revise and simulate for the system mathematical modal.

Keywords: farmland levelling machine, levelling knife, levelling part, inclination sensor, simulation

1 Introduction

China is a large agricultural country. The agriculture is the major water consumer and the surface irrigation occupies the dominant position in China's agricultural irrigation。According to the analysis, the field partial loss accounts for about 35% in the loss of irrigation water, so the field water-saving has the great potential. The cause of the field water loss includes that bedding block is too large, the land is not smooth, or the field exists a lot of sundries, such as waste plastic, hard straw, weeds, brick and tile, which the irrigation is not uniform and the deep seepage is serious. The research shows that when the land levelling error is less than 1~2cm, the inch water don't exposes the mud; the amount of shallow water irrigation can achieve the accurate water and the water saving is about 30~50%; it also can reduce fertilizer loss, improve the utilization ratio of the fertilizer. In the drought area, it can keep the moisture and improve the germination rate. At the same time, the levelling field can make the seeding depth uniformity and the seedling tidy and also make the crops get the required optimum water during the whole growth stage to improve the crop yield [1].

Since the 80's of 20 centuries, laser grader technology has attracted the wide attention from the scientific community and industry of china. Some large farms and enterprises imported the laser control grader to level the farmland [2].

Since the early 1990s, some schools and research institutions in China have also studied the laser grader. In 1996 Heilongjiang Academy of land reclamation sciences and Beijing Institute of Technology successfully developed agricultural laser grader of 1PTY-6. In 1997 Aviation Industry Corporation of China completed the project of the laser calibration grader [3]. In 2003 Northeast Agricultural University designed and developed the laser grader of 1PJY-3.0 [4]. Research mainly focused on the flat shovel. In 2007 South China Agricultural University designed a laser land leveller for paddy [5]. Since the late 1990s China Agriculture University devoted oneself to design and develop the farmland grader. The system adopts laser and the hydraulic system to level [2, 3, 6, 7].

In the nineteen seventies, The United States first applied the laser technology in agricultural grader, and had made the great economic benefit and social benefit [8]. America Spectral Precision Instrument Company successfully designed and developed the first set of the laser knife plate [3]. Because the laser knife plate levelling system had many unique technique effects and the great economic benefit, it obtained the fast development. In the 80's many foreign enterprises producing the grader is equipped with the laser levelling system, such as America's DRESSR, America's Spectra-Physics Company, America's TOPCON Laser Systems Company, German Boukema Company, Construction Machinery Company (Habaumag) and Swiss Firm Leica etc. In the 90's many developing countries also had used the laser land levelling technology, and achieved the good economic benefit, for example India, turkey and Pakistan etc. In American and Portugal, the use of the farmland levelling technique make the farmland irrigation uniformity improve from 17 to 20% and the crop yield increase by 7~ 31%; In India, the water saving is about 15 ~ 20%; in Turkey, the irrigation water efficiency is improved by 25 ~ 100%, the wheat yield is increased by 35 ~ 75%, the cotton yield is increased by 20 ~ 50% [2]. At present the grader has combined the advanced achievements in other fields in the developed industrial

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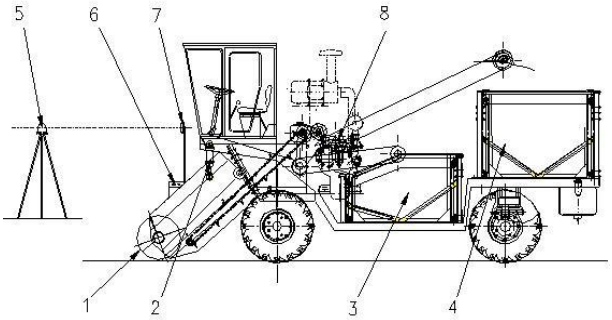
countries, led by the US, Europe and Japan. The advanced achievements include all wheel drive technology, laser automatic levelling device, electronic monitoring system etc. [7, 8, 9, 10, 11].

Based on the surface levelling machine that was successfully developed by the research group of the author without the sundries cleaning function [12, 13, 14, 15], the research group of the author studies and designs the self-propelled farmland levelling machine that not only can level but also clean the sundries. In addition to the recent studies of the research group, the domestic and foreign similar studies are the grader.

According to the request, this paper focuses on the levelling knife, the levelling part, the sundry separating device and the measurement and control system of laser and inclination sensor. At the same time, the hydraulic system mathematical modal is simulated through MATLAB.

2 Overall structure

Self-propelled farmland levelling machine includes levelling part, laser receiver, laser emitter, inclination sensor, hydraulic cylinder, sundry separating device, soil box and sundries box etc. The structure figure of self-propelled farmland levelling machine sees Figure 1. Levelling part installed in the front is connected with the frame by bolts. The hydraulic control system controls the levelling part to work on the plane that parallels with the datum plane. At the same time, the levelling part removes the mixed soil, and it is transported to the sundry and soil separator through the conveyor belt for the sundry and soil separation. Then the sundry and soil is respectively transported to the sundry box and soil box.



1. Levelling part 2. Hydraulic cylinder 3. Soil box 4. Sundry box
5. Laser emitter 6. Inclination sensor 7. Laser receiver
8. Sundry separating device
FIGURE 1 Self-propelled farmland levelling machine structure figure

3 Key technology

3.1 LEVELLING KNIFE

According to the working requirement, the levelling knife achieves two purposes. The first purpose is to cut the soil and collect the crushing soil containing the sundry and the second purpose is to ensure the soil surface roughness. In order to be able to efficiently cut the soil, using sliding mode; and in order to realize the broken soil collection function with the sundry, the levelling knife adopts a curved plates. Three-dimensional map of the levelling knife sees Figure 2.

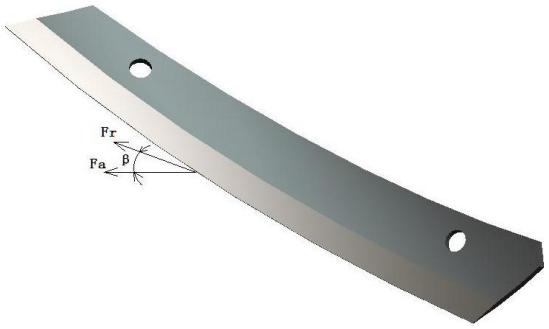


FIGURE 2 Three-dimensional map of the levelling knife

When self-propelled farmland levelling machine works, the point of the levelling knife firstly contacts with the soil, and then the edge contacts with the soil one by one, which changes the past scraper way and reduces the forward resistance.

Each piece of the levelling knife should ensure that the lowest position at any point in the blade is at the same altitude, or in the condition to keep the spindle levelling, the gyration radius is equal at each point on the edge. Because the spiral levelling knife has the helix angle (β) and the soil with the sundry is cut from the main forces in the normal direction of the blade, it is thrown in the same direction. Therefore, the helix angle can control the throwing direction of the crushing soil. The simulation and experiment results show that the helix angle is appropriate from 65° to 78°.

The absolute motion of the levelling knife is composed of two kinds of motion at work. One is the circular motion around the centre of the levelling shaft, another is the linear motion of the levelling knife with self-propelled farmland levelling machine. When self-propelled farmland levelling machine works two kinds of motion produces the effect for the levelling knife to generate the moving track of cosine cycloid. The moving track of cosine cycloid sees Figure 3. The moving equation of the levelling knife sees formula.1.

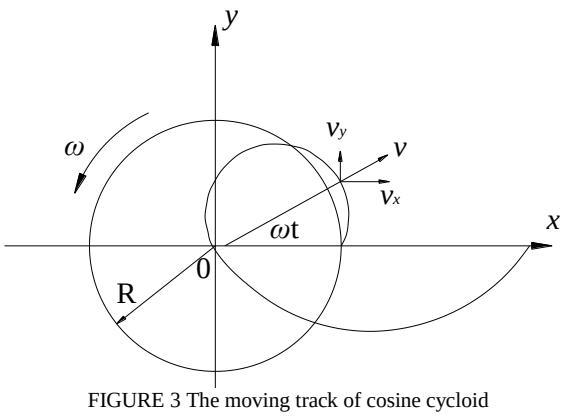


FIGURE 3 The moving track of cosine cycloid

$$\begin{cases} x = v_m t + R_i \cos \omega t \\ y = R_i \sin \omega t \end{cases}, \quad (1)$$

where v_m is the forward speed of self-propelled farmland levelling machine, ω is the angular speed of the levelling shaft, R_i is the rotating radius of the levelling knife.

The above equation is differentiated to obtain the speed of the levelling knife.

$$\begin{cases} v_x = v_m - R_i \omega \sin \omega t \\ v_y = R_i \omega \cos \omega t \end{cases}, \quad (2)$$

The levelling and cutting knife point speed is as follow:

$$v = \sqrt{v_m{}^2 + R_i{}^2 \omega^2 - 2 v_m R_i \omega \sin \omega t} . \quad (3)$$

3.2 LEVELLING PART

The spiral levelling knifes are uniformly and symmetrically installed on the levelling shaft. The three-dimensional map of the levelling part sees Figure 4. When self-propelled farmland levelling machine works, the levelling knifes cut into the soil in turn to realize the continuous and stable cutting and restrain the shock in cutting process. Because of the helix angle (β) the broken soil and the sundry is thrown along the direction of the vertical edge tangent. Therefore, it converges the middle symmetry plane in the thrown process and then is transported.

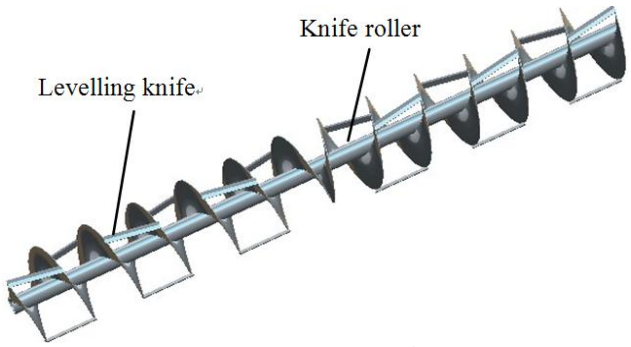
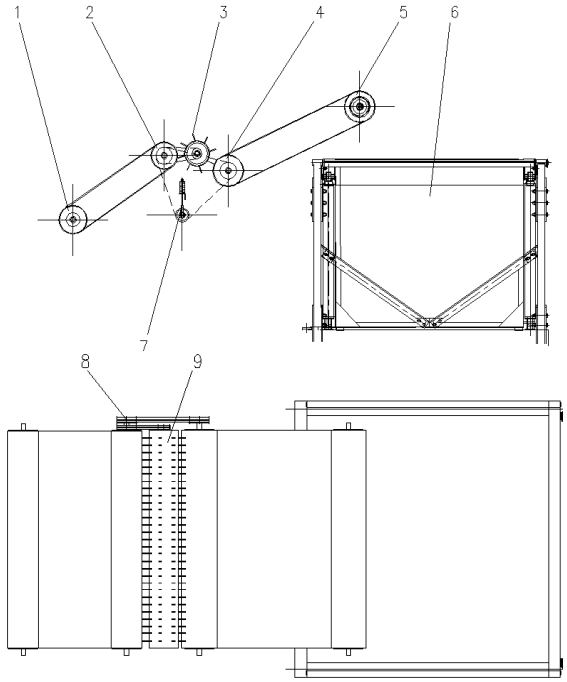


FIGURE 4 The three-dimensional map of the levelling part

The levelling parts configuration directly relates to smoothly cut the complex soil (containing the sundry) and reduce the power consumption. The research adopts the combination-levelling mode of the roller and cutter. The levelling knifes are uniformly arranged and welded in the spiral knife roller. The inclination angle of the levelling knife and the helix angle of the knife roller are equal. The theoretical analysis and practical experiment shows that the above arrangement mode can make the levelling knife easily cut the soil and reduce the power consumption.

3.3 SUNDRY SEPARATING DEVICE

At present, the grader can only level the soil and cannot clean up the sundry. In order to make up for the current grader flaw, the research group designs the sundry separating device. It is installed in the farmland-levelling machine and can effectively separate the soil and sundry. The device installs the separating roller of the soil and sundry with a certain amount of spring tooth in the middle in order to effectively separate the soil and sundry. Both ends of separating roller are respectively installed a conveyor belt. The front conveyor belt transports the soil with the sundry and the back conveyor belt transports the separated sundry to the sundry box. The sundry separating device sees Figure 5.



1, 2, 4, 5. Conveyor belt wheel 3. Spring tooth 6. Sundry box
7. Tension wheel 8. Power belt 9. Soil and sundry separating roller
FIGURE 5 Sundry separating device

3.4 MEASUREMENT AND CONTROL SYSTEM

The measurement and control system mainly includes inclination sensor, laser emitter, photo-electricity sensor, laser receiver, levelling control system, hydraulic servo system and levelling execution part. The Measurement and control system structure sees Figure 6.

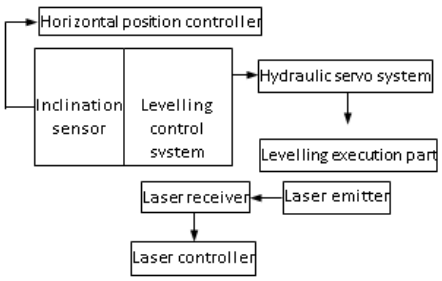


FIGURE 6 The system hardware structure

3.4.1 Laser working principle

Laser emitter emits a laser beam that can rotate 360° to scan and form the datum plane. Laser receiver is installed in the mast of the levelling part. Laser receiver receives the laser signal to transmit to the controller. If the above receiver receives the datum laser signal, which shows that the levelling part locates below the working plane and the correction signal improving the levelling part is transmitted to the hydraulic servo system, whereas if the under receiver receives the datum laser signal, which shows that the levelling part locates above the working plane and the correction signal reducing the levelling part is transmitted to the hydraulic servo system. After the hydraulic control system receive the correction signal from the levelling control system, the hydraulic servo system controls the levelling execution part to improve or reduce the levelling part to make the levelling part to work on the plane that parallels with the datum plane. When the middle receiver receives the datum laser signal, which shows that the levelling part levels. The laser working principle sees Figure 7.

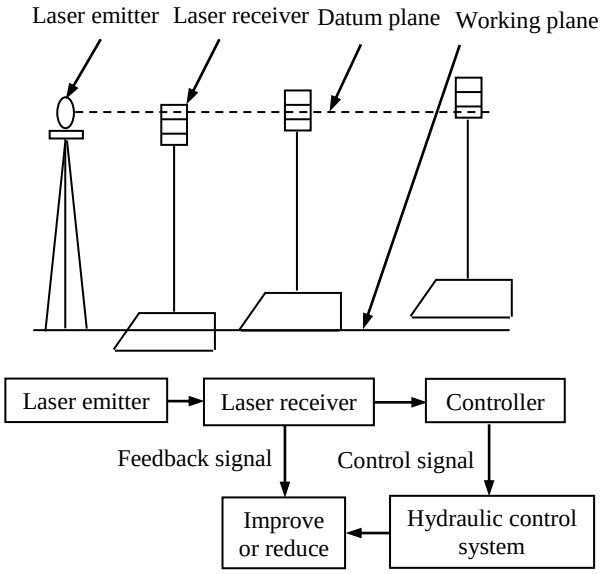


FIGURE 7 The laser working principle

3.4.2 Inclination sensor working principle

The paper uses the liquid pendulum inclination sensor to measure the inclination angle of the levelling part. The sensor is equipped with the conductive liquid in the glass shell, and has three platinum electrodes to connect with the external. Three electrodes are parallel to each other and have the equal distance. The conductive liquid of between two electrodes is equivalent to two resistors R1 and R2. When the levelling part levels, the electrode depth inserted into the conductive fluid is equal or R1 is equal to R2, and the control system doesn't output the signal, whereas when the levelling part inclines, the middle electrode depth inserted into the conductive fluid is fixed and the electrode depth inserted into the conductive fluid isn't equal on both sides or R1 isn't equal to R2.The control system outputs the signal. After the hydraulic control system receive the inclination signal from the levelling control system, the hydraulic servo system controls the levelling execution part to adjust the levelling part to make the levelling part to work on the plane that parallels with the datum plane. The inclination sensor working principle sees Figure 8.

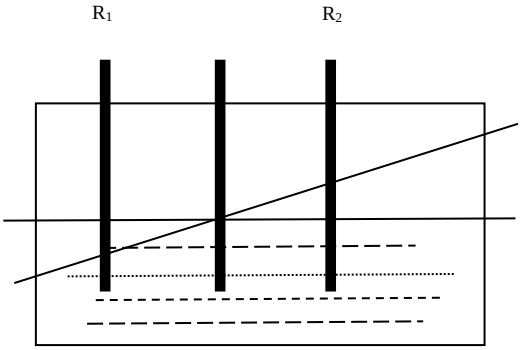


FIGURE 8 The inclination sensor working principle

4 Hydraulic Servo System Simulation

4.1 MATHEMATICAL MODEL OF HYDRAULIC SERVO SYSTEM

Self-propelled farmland levelling machine requires the high adjustment precision, the fast reaction and the easy parameter real-time feedback. So the hydraulic servo system adopts the closed-loop system of the valve control hydraulic cylinder to control the levelling execution part. The mathematical modal of the hydraulic servo system sees Figure 9.

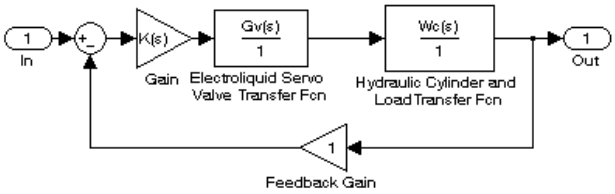


FIGURE 9 The mathematical modal of the hydraulic servo system

4.2 SYSTEM ANALYSIS, SIMULATION AND ADJUSTMENT

Using the control system toolbox compiles the applied program to analyse the opened loop transfer function of the hydraulic servo system. Step and bode figure of adjusting front and back mathematical model is separately drawn. Sees Figure 10 and Figure 11.

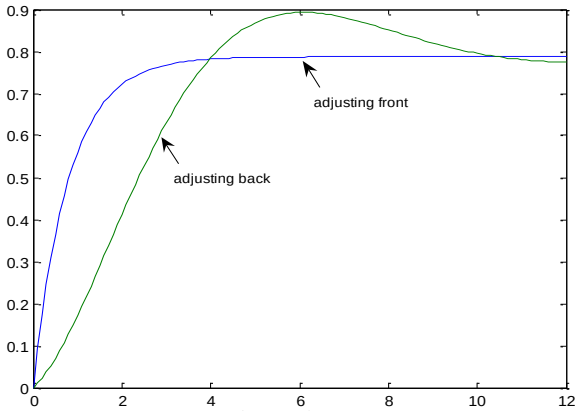


FIGURE 10 Step figure of mathematical model

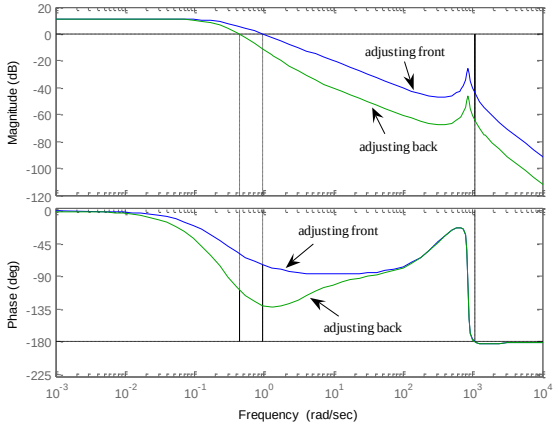


FIGURE 11 Bode figure of mathematical model

As we can see in Figure 10, the damping coefficient of adjusting front is approximate to one. The system has not the sigma. The system response is slow; the adjusting time is long and the fast reaction lags. Therefore, the control system need be adjusted.

After the system is adjusted, the adjusting function is as follow:

$$G_1(s) = \frac{0.08523s + 1}{1.023s + 1}, \tag{4}$$

According to Fig.10 after the system is adjusted, the damping coefficient is approximate to the optimal value. The adjusting time becomes short and the fast reaction moves up. And the sigma is small. According to Fig.11 after the system is adjusted, the control system is stable. The system can satisfy with the precision request of self-propelled farmland levelling machine.

6 Conclusions

According to the need of farmland levelling operation, the paper designs the levelling knife, the levelling part, the sundry separating device and the measurement and control system of the laser and inclination sensor. Self-propelled farmland levelling machine not only can level but also clean the sundries. At the same time, it greatly reduces the labour intensity of the farmland reclamation and improves the levelling efficiency. The hydraulic servo system simulation shows that the hydraulic control system is stable and reliable.

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