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Design, Simulation and Test of Self-propelled Farmland Levelling Machine

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Abstract

The paper carries a research on the self-propelled farmland levelling machine that not only can level the soil surface but also collect the sundries and designs soil-sundry levelling and collecting device, soil-sundry separating device and levelling control system based on laser and inclination sensor. The hydraulical motor drives the leveling and collecting knife shaft rotate to collect the sundries and roughly level the surface. The separating device separates the sundries and the broken soil through the vibration. The levelling control system adopts inclination sensor and laser emitter as the datum signal to form the datum plane. The hydraulic servo system controls the levelling device to work on the plane that parallels with the datum plane. At the same time, the paper establishes the hydraulic servo system mathematical modal and utilizes MATLAB to analyze, revise and simulate for the system mathematical modal. The test result shows that self-propelled farmland levelling machine is satisfied with the levelling request.

Keywords: *Levelling, Soil-sundry, Collecting, Laser, 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 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 the crops get the required optimum water during the whole growth stage to improve the crop yield [1].

Since the early 1990s, some schools and research institutions in China have also studied the laser grader. In 2003 Northeast Agricultural University designed and developed the laser grader of 1PJY-3.0 [2]. Research mainly focused on the flat shovel. In 2007 South China Agricultural University designed a laser land leveler for paddy [3]. In 2014 Nanjing Research Institute of Agricultural designed and developed the new laser grader [4]. China Agriculture University devoted oneself to design and develope the farmland grader. The system adopts laser and the hydraulic system to level [5, 6].

Agricultural grader, and had obtained the great economic benefit and social benefit. America Spectral Precision Instrument Company successfully designed and developed the first set of the laser knife plate [7]. Because the laser knife plate levelling system had

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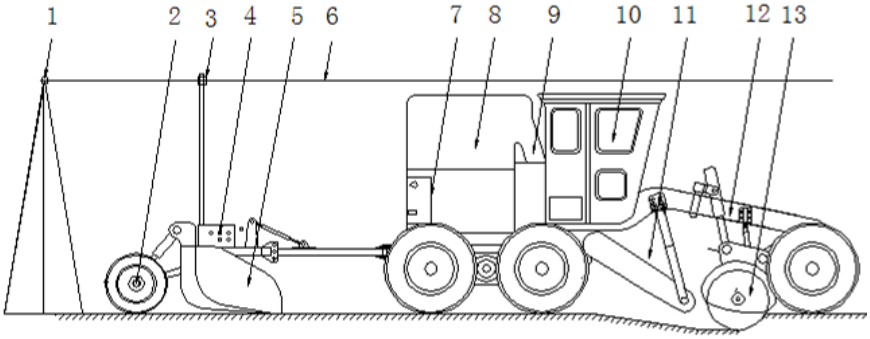
many unique technique effects and the great economic benefit, it obtained the fast development. In the 80's many foreign enterprises producing the grader is equipped with the laser levelling system, such as America's DRESSR, America's Spectra-Physics Company, America's TOPCON Laser Systems Company, German 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 [8].

Based on the surface levelling machine which was successfully developed by the research group of the author without the sundries collecting function [9,-13], the research group of the author studies and designs the self-propelled farmland levelling machine that not only can level the soil surface but also collect the sundries. In addition to the recent studies of the research group, domestic and foreign similar studies were the grader.

2. Overall Structure

Self-propelled farmland levelling machine includes soil-sundry levelling and collecting device, soil-sundry separating device, sundries conveying device, laser receiver, inclination sensor, sundries box *etc*. The overall structure figure of self-propelled farmland levelling machine sees Figure 1. Soil-sundry levelling and collecting device installed at the front collects the sundries and roughly levels the soil surface. Soil-sundry separating device separates the sundries from the soil through the vibration. And then the sundry is transported to the sundry box. Levelling device installed at the back precisely levels the surface and lightly rolls the soil. The hydraulic control system controls the levelling device to work on the plane that parallels with the datum plane.

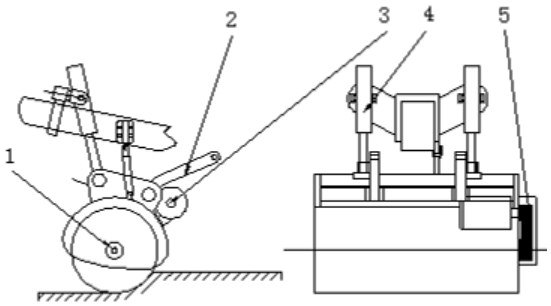


1. Laser emitter 2. Rolling and depth wheel 3. Laser receiver 4. Inclination sensor 5. Precise levelling device 6. Datum plane 7. Engine 8. Sundries box 9. Soil-sundry conveying device 10. Wheelhouse 11. Soil-sundry separating device 12. Vehicle frame 13. Soil-sundry levelling and collecting device

Figure 1. The Overall Structure Figure of Self-Propelled Farmland Levelling Machine

3. Soil-sundry Levelling and Collecting Device

Soil-sundry levelling and collecting device includes levelling and collecting knife shaft, front pole of levelling and collecting device, hydraulical motor, hydraulical cylinder, V strap *etc*. The soil-sundry levelling and collecting device sees Figure 2.The hydraulical motor drives the levelling and collecting knife shaft rotate to collect the sundries and roughly level the surface.



1. Levelling and collecting knife shaft 2. Front pole 3. Hydraulical motor
4. Hydraulical cylinder 5. V strap

Figure 2. Soil-Sundry Leveling and Collecting Device

3.1. Levelling and Collecting Knife

According to the working requirement, the levelling and collecting knife achieves two purposes. The first purpose is to cut the soil and collect the broken soil containing the sundry and the second purpose is to roughly level the soil surface. In order to be able to efficiently cut the soil, using sliding mode; and in order to collect the broken soil with the sundry, the levelling and collecting knife adopts a curved plates. Three-dimensional map of the levelling and collecting knife sees Figure 3.

Figure 3. Three-Dimensional Map of the Levelling and Collecting Knife

When self-propelled farmland leveling machine works, the point of the levelling and collecting 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 and collecting 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. So the helix angle can control the throwing direction of the broken soil. The simulation and experiment results show that the helix angle is appropriate from 65° to 78°.

The absolute motion of the levelling and collecting knife is composed of two kinds of motion at work. One is the circular motion around the centre of the levelling and colleting shaft, another is the linear motion of the levelling and collecting knife with self-propelled farmland levelling machine. When self-propelled farmland levelling machine works two kinds of motion produces the effect for the levelling and collecting knife to generate the moving track of cosine cycloid. The moving track of cosine cycloid sees Figure 4. The moving equation of the levelling and collecting knife sees formula 1.

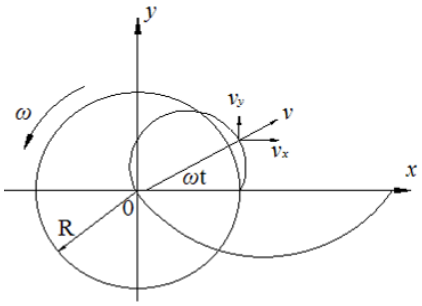


Figure 4. The Moving Track of Cosine Cycloid

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

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

The above equation is differentiated to obtain the speed of the levelling and collecting 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 collecting 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 and Collecting Knife Shaft

The spiral levelling and collecting knifes are uniformly and symmetrically installed on the knife shaft. Three-dimensional map of the levelling and collecting knife shaft sees Figure 5. When self-propelled farmland levelling machine works, the levelling knifes cut the soil in turn 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. So it converges the middle symmetry plane in the thrown process and then is transported and collected.

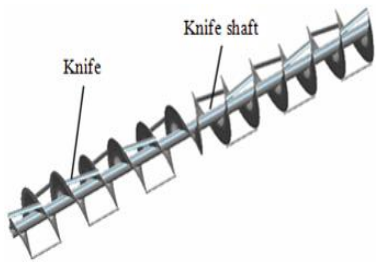


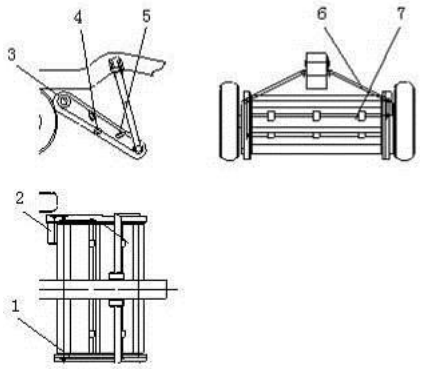
Figure 5. Three-Dimensional Map of the Levelling and Collecting Knife Shaft

The levelling part 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 knife and the shaft. The knife is uniformly arranged and welded in the spiral knife shaft. The inclination angle of the knife and the helix angle

of the knife shaft are equal. The theoretical analysis and practical experiment shows that the above arrangement mode can make the knife easily cut the soil and reduce the power consumption.

4. Soil-sundry Separating Device

Soil-sundry separating device includes chain, hydraulical motor, driving shaft, supporting wheel, vibrating wheel, supporting pole, conveying chain *etc*. Soil-sundry separating device sees Figure 6. The conveying chain is composed of some steel bars which are installed on both sides of the chain and the diameter is 10mm. The clearance between steel bars can be adjusted in order to satisfy with the work requirement. The elliptic vibrating wheel located in the conveying chain directly contacts with the steel bar and is driven by the conveying chain to ensure the steel bar periodically vibrate in order to separate the sundries and the broken soil. The amplitude of the vibrating wheel depends on the ratio of long and short radius, the number of the vibrating wheel, the tension degree and speed of the conveying chain *etc*.



1. Chain 2. Hydraulical motor 3. Driving shaft 4. Supporting wheel 5. Vibrating wheel 6. Supporting pole 7.Conveying chain

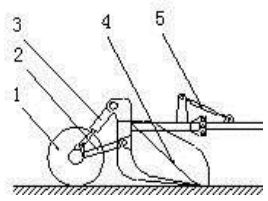
Figure 6. Soil-Sundry Separating Device

When working, the broken soil and the sundries are thrown to the conveying chain. In the conveying process, the broken soil falls from the clearance between steel bars and the sundries is conveyed to the sundries box. At the same time, the vibrating wheel up and down vibrates in order to enhance the ability of the separation of the crashed soil and the sundries.

5. Levelling Control System

5.1. Levelling Device

Levelling device installed on the back of self-propelled farmland levelling machine includes rolling and depth wheel, connecting rob, hydraulic cylinder, supporting and adjusting rod. The structure diagram of levelling device sees Figure 7. In the working process, levelling part is controlled by the hydraulic cylinder to adjust the levelling precision. Levelling device connects the self-propelled farmland levelling machine with the rear suspension. According to the working situation, the self-propelled farmland levelling machine adjusts the height of the rear suspension in order to make the levelling part always keep the best levelling angle.



1. Rolling and depth wheel 2. Connecting rob 3. Hydraulic cylinder 4. Levelling part 5. Supporting and adjusting rod

Figure 7. The Structure Diagram of Levelling Device

5.2. Measurement and Control System

The measurement and control system mainly includes inclination sensor, laser emitter, photo-electricity sensor, laser receiver, levelling control system, hydraulic cylinder and levelling part. The Measurement and control system structure sees Figure 8.

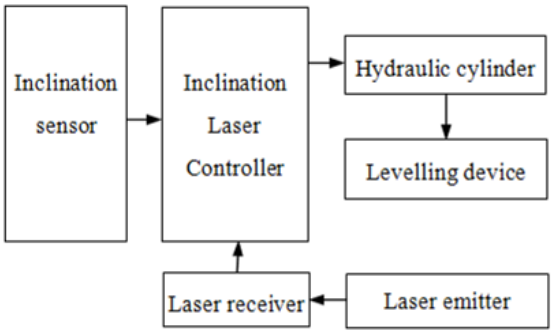


Figure 8. The System Hardware Structure

The levelling control system adopts microprocessor of ARM the model number of which is LPC2102 and built-in control software. According to the system function request, controller exports the corresponding control signal to real-timely control the hydraulic servo system of the self-propelled levelling machine based on location deviation and levelling inclination signal.

5.2.1. Inclination Sensor Signal Treatment: In the level and vertical direction inclination angle of x, y direction which is measured by inclination sensor exports the milli-voltage. After the milli-voltage is enlarged by amplifier, the amplifying voltage is imported to frequency transformer. And then through the photo-isolator the pulse is read by the levelling control system. After the upper treatment the data error which is induced by electromagnetic disturbance is effectively reduced.

5.2.2. Filter Treatment: The disturbing signal of natural light is stronger more than laser signal. So the light signal must carry through the filter treatment. Because laser transmission rate of 635nm wave is strong, laser receiver adapts the big bandwidth filter chip. Considering the slope incidence of laser, the central wave of filter chip is 670nm. When the slope incidence angle of laser beam is 45°, the central wavelength of filter chip changes from 670nm to 600 and the peak transmission rate reduces a percentage of 10. So the semi-bandwidth of filter chip is 100nm.

5.2.3. Laser Receiver: Laser receiver is an important composing part of levelling control system. When the system works, laser emitter scans and transmits laser beam to form a laser beam datum plane of level and uprightness above the operation plane. Laser

receiver connects with levelling control system and laser transmission and real-timely accepts the faint low-frequency. After it is treated, the location deviation is transmitted to levelling control system. Low-frequency laser signal is transformed to get the faint analogy signal by photo-electricity sensor. The faint analogy signal is carried through amplitude modulation. And then amplitude modulation signal passes low-noise pre-main amplifier, rectifier circuit and stretching circuit in turn. Last levelling control system exports the control signal to the hydraulic servo system.

5.2.4. Weak Electricity Treatment: When laser emitter works, it exports continuous laser beam. After being reflected by pentprism, laser beam diverts 90^{o}. The signal laser receiver accepts is the 10 hertz pulse. After being filtered, laser signal translates analogy signal through the photo-electricity sensor. Because analogy signal contains the noise of photo-electricity sensor and amplifier etc, its signal-to-noise ratio is very low. And the low and faint signal of low-frequency is carried through amplifying, filter and shaping treatment. In faint detection system, the output port of sensor connects with a low-noise prefix amplifier. It amplifies the faint electricity signal that is exported by photo-electricity sensor and makes photo-electricity sensor offset and match with impedance. In the system, the request of low-noise prefix amplifier is as follows: compactness, close sensor, nicer ground and shield. Adopting high gain amplification circuit furthermore amplifies the faint signal. Band filter is designed for eliminating the diversified interference signal. Comparator circuit transforms the analogy signal into the regular pulse signal. And then pulse signal is treated by pulse spreading circuit. Last pulse spreading signal is imported to the levelling control system.

5.3. Laser Working Principle

Laser emitter emits a laser beam that can rotate 360° to scan and form the datum plane. 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 levelling control 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 levelling control 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 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 9.

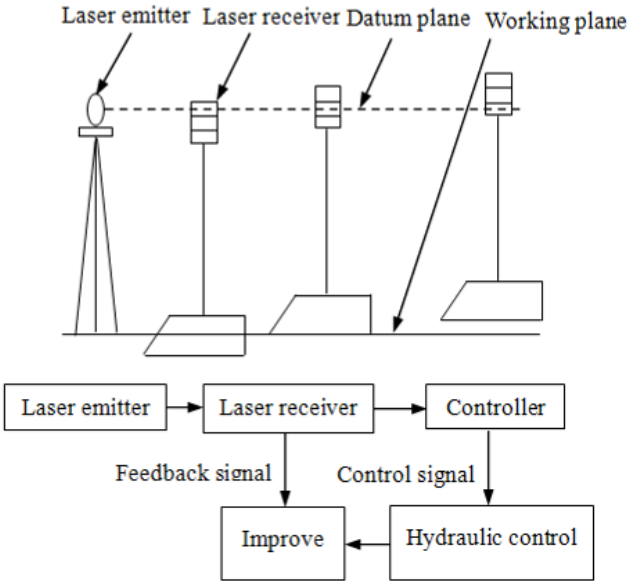


Figure 9. The Laser Working Principle

5.4. 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 R_1 and R_2. When the levelling part levels, the electrode depth inserted into the conductive fluid is equal or R_1 is equal to R_2, and the levelling 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 R_1 isn't equal to R_2.The levelling 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 work on the plane that parallels with the datum plane. The inclination sensor working principle sees Figure 10.

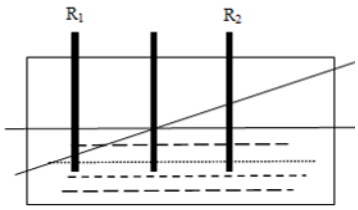


Figure 10. The Inclination Sensor Working Principle

6. Hydraulic Servo System Simulation

6.1. 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 11.

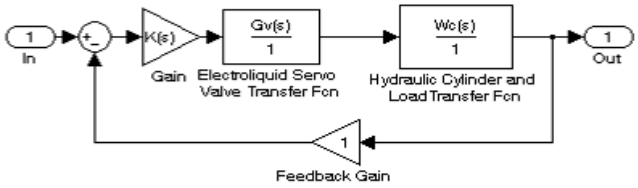


Figure 11. The Mathematical Modal of the Hydraulic Servo System

6.2. System Analysis, Simulation and Adjustment

Using the control system toolbox compiles the applied program to analyze the opened loop transfer function of the hydraulic servo system. Step and bode figure sees Figure 12 and Figure 13.

As we can see in Figure 11, the damping coefficient of adjusting front is approximate to 1. The system hasn't the sigma. The system response is slow; the adjusting time is long and the fast reaction lags. So the hydraulic servo control system need be adjusted.

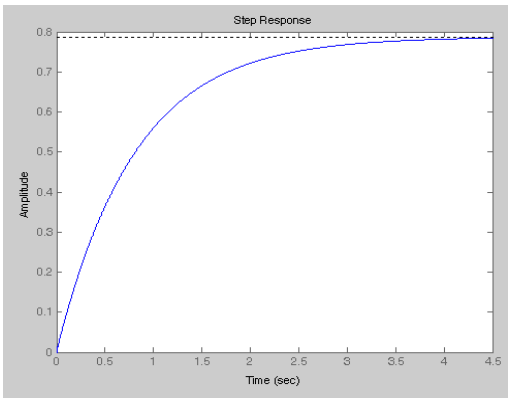


Figure 12. Step Figure

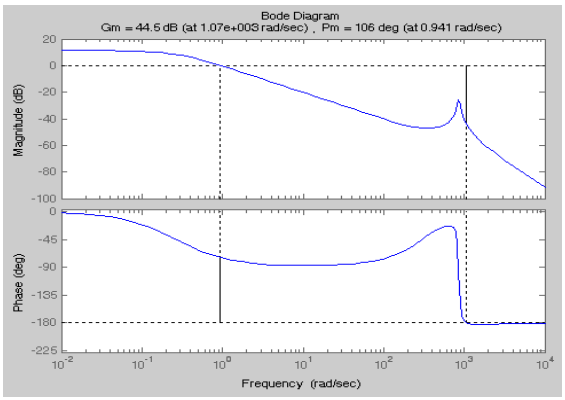


Figure13. Bode Figure

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

$$G_1(s) = \frac{0.08643s + 1}{1.143s + 1}$$

The adjusted step and bode figure sees Figure 14 and Figure 15.

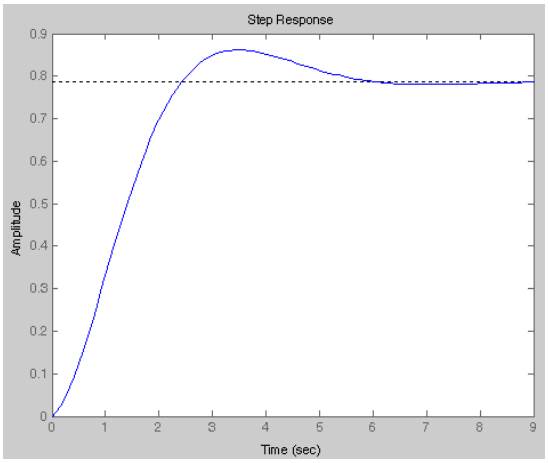


Figure14. Adjusted Step Figure

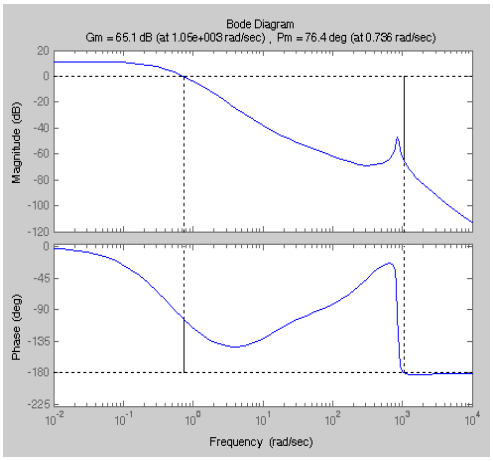


Figure15. Adjusted Bode Figure

According to Figure 14 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 Figure 14 after the system is adjusted, the hydraulic servo control system is stable. The system can satisfy with the precision request of self-propelled farmland levelling machine.

7. Leveling Test

After electing the original foundation and artificially leveling a datum plane, the self-propelled levelling machine levels the surface. The sampling area is 100m×100m. The sampling data sees Table 1.

Table 1. Leveling Test Sampling Data (Unit: mm)

h_{ij}	j=1	j=2	j=3	j=4	j=5	j=6	j=7	j=8	j=9	j=10
i=1	14.5	8.0	13.4	15.0	15.5	14.8	14.8	14.5	14.6	14.5
i=2	13.9	13.1	11.0	14.9	13.2	14.2	14.6	15.3	14.9	15.1
i=3	11.8	14.5	12.6	14.6	14.8	13.4	14.5	13.8	14.7	15.2
i=4	14.9	13.8	9.8	15.5	13.5	12.8	14.0	14.2	14.8	14.6
i=5	13.8	13.3	12.0	15.2	12.9	11.2	13.8	13.8	15.2	14.5
i=6	14.7	12.9	11.7	13.5	14.0	12.3	12.5	14.3	13.1	13.8
i=7	13.1	12.3	10.8	13.9	13.9	11.8	14.2	11.8	9.0	14.1
i=8	14.2	13.0	10	14.1	13.8	12.6	15.1	12.9	12.3	12.5
i=9	14.1	14.2	10.8	14.5	13.1	12.7	12.8	12.8	13.1	13.8
i=10	14.5	12.8	12.3	13.6	12.5	10.0	14.1	15.2	14.6	15.0

The Geomorphologic map after leveling test sees Figure 16. As shown in Figure 16, the levelling error variance is satisfied with the levelling request.

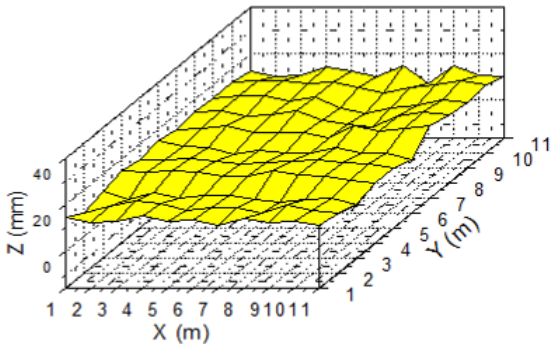


Figure 16. Geomorphologic Map After Leveling Test.

8. Conclusions

According to the need of farmland levelling operation, the self-propelled farmland levelling machine that not only can level the surface but also collect the sundries is designed. The paper designs soil-sundry levelling and collecting device, soil-sundry separating device, levelling device, levelling control system based on laser and inclination sensor. The system realizes the united measurement and control of inclination sensor and laser. The self-propelled levelling machine adopts laser emitter as signal source to make levelling part level. The balance of the self-propelled levelling machine adopts inclination sensor as signal source. This system is already applied by trench-levelling machine also. The hydraulic servo system simulation shows that the hydraulic control system is stable and reliable. The test result shows that the levelling control system is satisfied with the levelling request.

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