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Design and Study on Dynamic Measuring System for Field Surface Roughness

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Abstract
Explore the adaptability and relationship of planter to field surface roughness. Through field test of the designed dynamic testing system of field surface roughness, the two types of field surface roughness were detected on the original field surface roughness formed by the working rotary and the field surface roughness formed after planters work. The transfer functions of the system were established, and the dynamic characteristics of the system were analyzed. The results show that, the system is a linear one with the typical first order feature. The dynamic characteristics of the systems such as response speed, frequency bandwidth and thickness of covering soil and other performance indicators are able to meet the requirements of agricultural technology.

Keywords: *field surface roughness, dynamic measuring system, response, transfer function*

1. Introduction

The working quality of the planter is directly reflected with whether soil covering thickness of the seed can meet the agricultural requirement [1, 2], while the field surface roughness is the main factor to affect the soil covering thickness of the planter. The adaptability of the developed taped type planter for field surface roughness is one of main dynamic performance indexes of the planter [3, 4]. Currently, the in-depth research on detection and analysis method of the surface roughness of pavement and farmland were ever carried out [5-7], but little research is focused on the effect of surface roughness on agricultural machinery working performance, and most researches are in the qualitative analysis level [8-10]. In order to explore the adaptability of the planter for surface roughness and to improve the operating performance of the working parts, the designed direct seeding machine is used as the research object to explore its working performance in the process of ditching, covering and compacting. This work can provide technical reference to improve the adaptability of the planter for surface roughness.

2. Design of the Test System
2.1. Composition and Structure

The test system, which is composed of two parts of hardware system and software system, has the functions of the strain signal dynamic acquisition, preprocessing and data analysis. According to the test objectives and requirements, and combined with the structure and working situation of the direct seeding machine, the structure of the designed dynamic testing device and installation on the planter is as shown in Figure 1. The dates acquisition hardware system is composed of the sensor (Taiwan WDS36-V/A), JKU-12 data acquisition card and a portable computer.
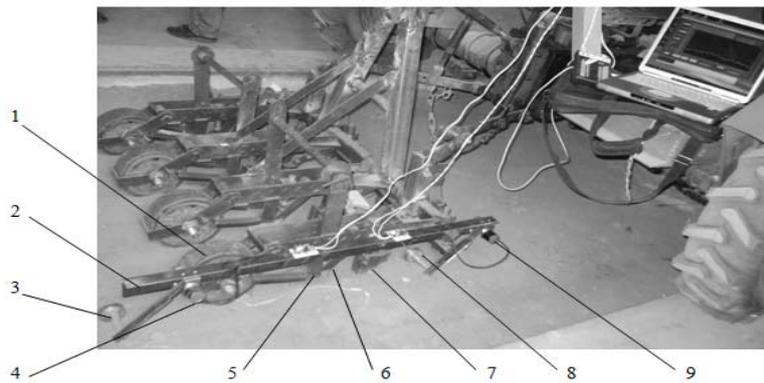
1. Compaction wheels 2. Bracket 3. Field surface roughness testing device after the compaction
4. Rear sensor 5. Covering soil device 6. Opener 7. Anti-blocking device
8. Field surface roughness testing device of the original surface roughness 9. Before sensor

Figure 1. Test System Structure and Sensor Layout

2.2. Working Principle

The function and work flow of the system is shown in Figure 2. Setting the field surface roughness as input, and the soil covering thickness as output, the study of the dynamic simulation test is carried out on the soil-planter system. Through establishing the mathematical model of the soil covering thickness of the planter, the soil covering situation is explored. In the detection process of the test system, the test device moves with the planter. The values of the original field surface roughness and field surface roughness after the compaction is turned into voltage signal and inputted to the data acquisition system by the surface roughness tester, angle sensors and data acquisition card, then the data is processed with the analysis software, and the result is displayed. Based on the results of the analysis, the mathematical model of field surface roughness and ditch bottom roughness is established. The information transfer model and signal detection node of the test system is shown in Figure 2, the solid parts are information transmission lines of the system, dotted lines are the links for signal detection and processing analysis. In Figure 2, y_n is the original field surface roughness, y_1 is the formed field surface roughness after the anti-blocking device working, y_2 is formed ditch bottom roughness after the opener working, y_3 is the formed field surface roughness after the covering soil device working, y_4 is the formed field surface roughness after the compaction wheels working, s_1 is the formed depth of the furrow by opener, s_2 is the soil covering thickness after the compaction.
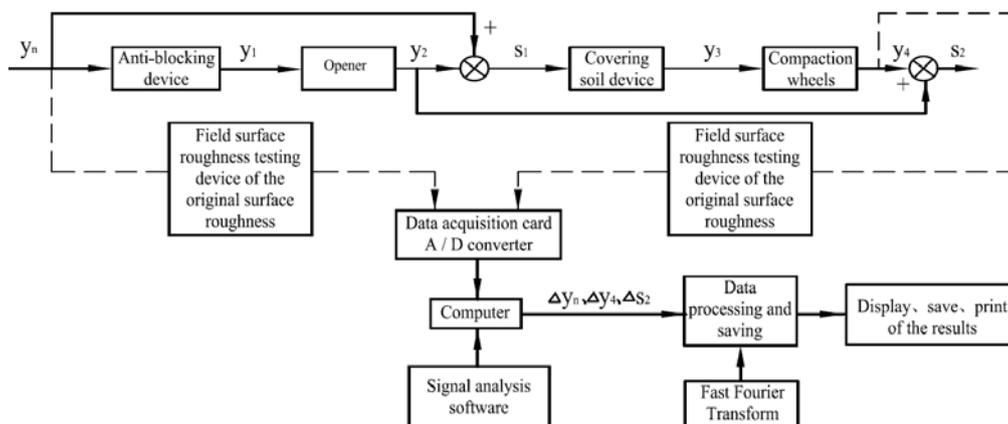
Figure 2. Information Flowing Model of the System

2.3. The Calibration of the Test System

The data acquisition system consists of the sensors and relevant measuring instrument. In order to ensure acquisition accurate, the performance of the system must be known in accuracy before the date acquisition, so the calibration of the sensors is needed. Calibration usually includes the static calibration and dynamic calibration [11-14]. According to the actual working conditions and the requirements of the test system, the static calibration is used in the test. The analysis results of regression curve of the calibration are shown in Table 1.

Table 1. Regression Analysis Result Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	0.01154
2	1.000[a]	1.000	1.000	0.02212

ANOVA[b]

Model	Sum of squares	df	Mean Square	F	Sig.
Regression	22.966	1	22.966	172563.8	.000[a]
Residual	.002	13	.000		
Total	22.968	14			
Regression	14.949	1	14.949	30563.033	.000[a]
Residual	.005	11	.000		
Total	14.954	12			

Coefficients[a]

Model	Unstandardized Coefficients		Standandized Coefficients	t	Sig.
	θ	Stad. Error	Beta		
1 (Constant)	-.109	.008		-13.377	.000
θ	.057	.000	1.000	415.408	.000
2 (Constant)	-1.606	.021		-77.567	.000
θ	.057	.000	1.000	174.823	.000

In Table 1, model 1 is regression equations of front angle sensor, and model 2 is the regression equation of rear angle sensor. It can be obtained from Table 1 (Model Summary) on fitting situation of the linear regression models of two curve, the correlation coefficient R were 1.00, the determination coefficient R^2 were 1.00, so the model fitting effect is very ideal. From the variance analysis table (ANOVA[b]), it can be seen that the each sum of squares of deviations were 22.966 and 14.949, the each sum of squared of residuals were 0.002 and 0.005, and the each sum of squares of regression were 22.968 and 14.954. In the significant test of regression equation, statistics are respectively F=172563.8 and F=30563.03, the corresponding confidence levels are much less than the confidence level (0.05), so the model of the two curve equations is extremely significant. From the testing result table (Coefficients[a]), it can be obtained that T test is used to significant test of regression coefficients, the standardization and not standardized results are given to coefficient of regression equation, the constants of the not standardized regression equation were -0.109 and -1.606, variable coefficients were 0.057. In the test results of the regression coefficient, the confidence levels of the constant and variable coefficient are much less than the confidence level (0.05), so the constant and variable coefficient is significantly.

Therefore, the calibration results of angle sensors of the system are shown:
The regression equation of the before sensor can be obtained.

$$V = 0.057\theta - 0.109 \tag{1}$$

The regression equation of the rear sensor can be obtained.

$$V = 0.057\theta - 1.606 \tag{2}$$

2.4. The Mathematical Model of Field Surface Roughness

When testing surface roughness, the test wheel on the testing device is up and down with the change of field surface, driving the link rod and link rod axis rotation. Two angle sensors are respectively installed in the two link rods axis, and converted variable amount into voltage. The voltage is converted into analog amount by high magnification, and sent to the data analysis software to be processed. As shown in Figure 3, the relationship of the field surface roughness and the rotation angle can be obtained.
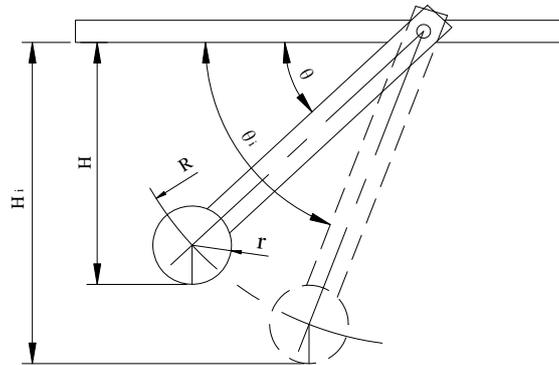
Figure 3. Schematic Diagram of the Surface Height Changes

$$H_0 = R\sin\theta_0 + r \tag{3}$$

$$H_i = R\sin\theta_i + r \tag{4}$$

The field surface variation amount can be obtained.

$$h_i = H_i - H_0 = R(\sin\theta_i - \sin\theta_0) \tag{5}$$

In formula: H_0—The height of test bracket to the original field surface; H_i—The height of test bracket to the field surface after the compaction; R—rotation radius of the connecting rod shaft; r—the radius of the test wheel; θ_0—starting angle; θ_i—rotation angle; h_i—variation value of the field surface。

The relationship of the field surface roughness and output voltage can be derived from (1), (2), and (5).

Front：

$$h_{qi} = R(\sin\frac{V_i + 0.109}{0.057} - \sin\frac{V_0 + 0.109}{0.057}) \tag{6}$$

Rear：

$$h_{hi} = R(\sin\frac{V_i + 1.606}{0.057} - \sin\frac{V_0 + 1.606}{0.057}) \tag{7}$$

The change of tractor vibration and soil resistance on the ground has certain influence on the field surface roughness after the compaction and soil covering thickness. However, the hydraulic suspension system of the connection tractors and implements is in floating state in operation, and the depth of ditching and covering soil is very shallow (about 30mm), in order to simplify the problem, the two factors are ignored in the process of establishing system information model. Therefore, the ditch bottom roughness is the field surface roughness before the ditching in the test. Test initial position is set as the base surface, the initial entering soil

depth of the opener is adjusted to 30mm, therefore, so the distances of the ditch bottom to field surface can be obtained.

$$h_{gi} = h_{qi} + 30 \qquad\qquad (8)$$
$$= R(\sin\frac{V_i + 0.109}{0.057} - \sin\frac{V_0 + 0.109}{0.057}) + 30$$

3. Test and Result Analysis of Field Surface Roughness
3.1. Experimental Materials and Methods

Test was carried out at the soil bin test station of Shenyang Agricultural University laboratory. Rotary cultivator operations, with 0.5m deep of soil, and artificial smooth field surface, the standard deviation of field surface roughness less than 3cm. Artificial watering, compaction, the moisture content, compactness and bulk density of the soil is made to uniform with the actual situation in field, and meet the requirements of soil tillage. The test device include the direct seeding machine, JKU-12 data acquisition card, data receiver (portable computer), dynamic test apparatus, meter, small shovel, two angle sensors (DS36-V/A), stabilized power supply and connecting wires, etc.. The forward speed of testing vehicle is 0.25~0.30m/s, the sampling frequency is 500Hz, depth of the Opener is 3cm, and the testing length of field surface roughness is 10m. In the experiment, JKU-12 data acquisition card is used for data acquisition. The front angle sensor is connected with channel B, and the rear angle sensor is connected with channel A. In order to eliminate the errors of manufacture and installation in testing system, the system is calibrated. The experiment was repeated for 4 times, experimental data was analyzed with SPSS software [15].

3.2. Results and Analysis
(1) The results and analysis of field surface roughness

4 groups of the field surface roughness data before and after ditching were collected. The first group is analyzed. The transmitted data of front and rear angle sensor has some certain time difference, Channel A data are pushed forward by calculation to make them consistent with Channel B in the time domain. The time domain curve was showed in Figure 4.
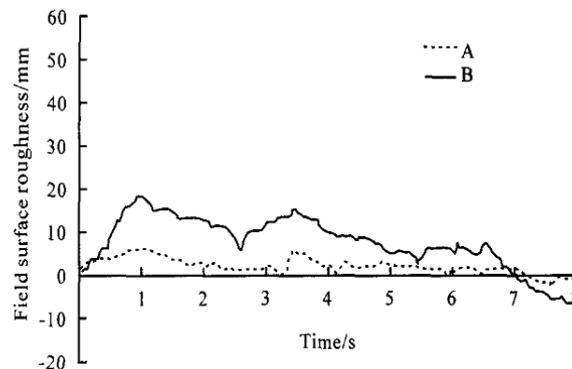
A. Field surface roughness after the compaction; B. The original field surface roughness

Figure 4. Change Scale of Surface Roughness in Time-domain

In order to analyze the desirability of sampling dates, the statistical analysis of the dates is done. The result is showed in Table 2.

Table 2. The Statistical Analysis of the Field Surface Roughness

Channel A		Channel B	
Average	2.309305	Average	7.66646
Standard error	0.023042	Standard error	0.096207
Median	2.2494	Median	8.0008
Standard deviation	1.45729	Standard deviation	6.084638
Coefficient of variation	0.631051	Coefficient of variation	0.79367
Variance	3.088068	Variance	37.02283
Kurtosis	0.037977	Kurtosis	-0.19607
Skewness	0.151127	Skewness	-0.60522
Minimum value	-1.9734	Minimum value	-6.4721
maximum value	6.3661	maximum value	18.7711
observation numbers	4000	observation numbers	4000

From Figure 4 it can be seen: the surface fluctuation amplitude is -10~20mm before ditching, the surface fluctuation amplitude is only -5~5mm after the compaction, the field surface roughness after the compaction is obviously decreased. After analysis of the statistical in table 2 it can be obtained the average of the channel A and channel B were each 2.31 and 7.67 respectively, the standard deviation were each 1.46 and 6.08, the kurtosis were each 0.04 and -0.20, the skewness were each 0.15 and -0.61, the coefficient of variation were each 0.63 and 0.79. The results showed that the compaction wheel has a good compaction effect, it can balance the seeding depth, and create a good environment for the growth of seeds.

(2) Spectral analysis of field surface roughness

The self-power spectrum of field surface roughness of before and after planter working can be obtained by the theoretical analysis and software calculation, as shown in Figure 5. It can be seen from the graph that the power spectrum density curves had two peaks, and the frequency is the same. Before working of the planter, the maximum frequency (main frequency) is 0.0625Hz, the maximum amplitude is 7.549, frequency has also a certain distribution between 1~3 Hz. The frequency is more than 3Hz, amplitude tends to 0, and the cut-off frequency of the system is about 1.5Hz. After working of the planter, the maximum frequency (main frequency) is 0.0625Hz, the maximum amplitude is 2.542, frequency is more than 1Hz, amplitude tends to 0, the cut-off frequency of the system is about 0.6Hz. From the two power spectrum image, it can be known that the two main frequency of field surface roughness are completely consistent before and after planter working. It is indicated that the system has good linear characteristics.
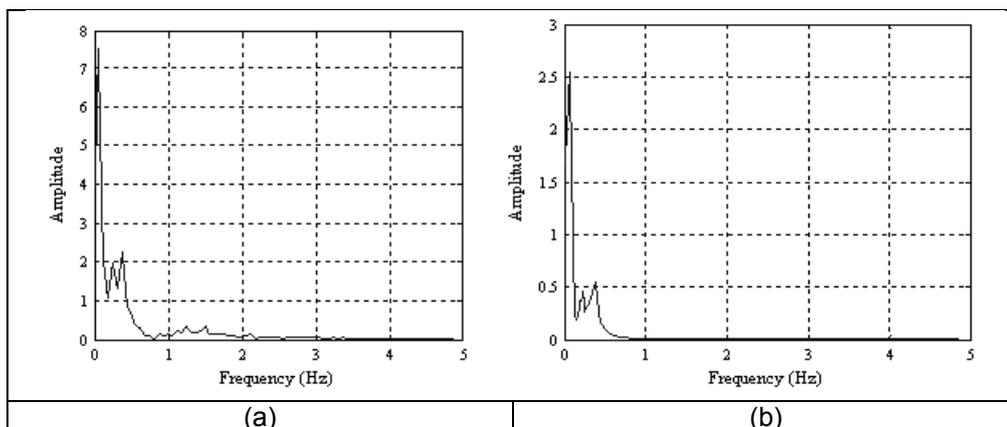
Figure 5. Self-power Spectrum of field Surface Roughness of the before and after Planter Working

(3) The effect of the original field surface roughness to soil covering thickness

According to the theory of linear systems, mathematical model between input and output can be established by the transfer function, and be used to study the dynamic characteristics of the system. Through the amplitude-frequency characteristic curve of the system and the structure characteristics, the system is preliminarily determined to be consisted of inertia, frequency characteristics can be obtained.

$$G(j\omega) = \frac{k}{j\omega T + 1} = \frac{K}{\omega^2 T^2 + 1} - j\frac{K\omega T}{\omega^2 T^2 + 1} \tag{9}$$

The amplitude frequency characteristics of the system can be obtained.

$$A(\omega) = \frac{K}{\sqrt{(T\omega)^2 + 1}} \tag{10}$$

Phase frequency characteristic can be obtained.

$$\varphi(\omega) = \arctan \omega T \tag{11}$$

The transfer function of the system can be obtained.

$$G(s) = \frac{k}{Ts + 1} \tag{12}$$

The result is obtained by statistical analysis of data, as shown in Table 3.

Table 3. The Statistical Analysis of the Transfer Function Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
k	0.566	0.019	0.524	0.607
T	0.106	0.016	0.072	0.140

ANOVA(a)

Source	Sum of Squares	df	Mean Squares
Regression	2.609	2	1.305
Residual	0.025	13	0.002
Uncorrected Total	2.634	15	
Corrected Total	0.264	14	

Dependent variable: z
a R squared = 1 - (Residual Sum of Squares) /(Corrected Sum of Squares) = .907

The standard error, 95% confidence interval and the relationship array between the parameters can be seen from the parameters estimated table of the Table 3. The estimation values of the parameters are k=0.57, T=0.11. When the original field surface roughness is as input and the field surface roughness after compaction is as output, the transfer function of field surface roughness of before ditching and after compaction can be obtained by the above analysis.

$$G(s) = \frac{Y_n(s)}{Y_4(s)} = \frac{0.57}{0.11s + 1} \tag{13}$$

The model is identified by the variance analysis table (ANOVA[a]). The absolute coefficient reaches 0.91 with the good .fitting degree of model. Similarly, the original surface roughness as input and soil covering thickness as output, the established transfer function model of the system can be obtained.

$$G_2(s) = \frac{Y_n(s)}{S_2(s)} = \frac{0.95}{0.11s + 1} \tag{14}$$

Formula (13) and (14) show that these 2 systems are both composed of a proportional series and a first-order series connection. Time constants of the system are T = 0.11s, but their ratio coefficient is different. When initial depth of the opener is adjusted to S1 = 30 mm, the average of the soil covering thickness is 28.36 mm, the standard deviation is 4.84 mm, the coefficient of variation is 17.07%.

4. Conclusion

The design and development of the dynamic testing system, and based on the correlation between surface roughness, the seeds covered soil depth, established the mathematical function model of the soil thickness of covering seed. By testing the system on the machine in the field before and after surface roughness test results, the mathematical function model was modified. The test results prove that the mathematical model is reliable, and the testing system precision is higher.

Acknowledgements

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