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DYNAMIC ANALYSIS AND EXPERIMENTAL RESEARCH OF VIBRATORY SUBSOILER SYSTEM

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ABSTRACT

Soil has elastic-plastic deformation under vibrating working condition. And the acting force between the soil and the vibrating subsoiler parts is of complication. In order to study the effect of the material acting force to the vibrating subsoiler system kinetics features, this paper establishes the vibrating subsoiler system mechanics model considering material acting force. It adopts numerical integral to answer and analyze this model and verify the correctness of the model through comparison of the simulation data and experimental data. In order to research the relationship among the vibration frequency, forward velocity and tractive resistance of tractor in the farming process, the paper regards 1SZ-160 tillage implement as the research object, uses the in-house designed Π-shaped frame force measuring system to test the tractive resistance in different vibration frequencies and forward velocities, and obtains the vibration data of the base of the tractor by the vibration test system. The test result shows that in the identical vibration working condition and with the increase of the forward velocity, the tractive resistance is increased slowly, in the working condition of having the stated forward velocity and with the increase of the vibration frequency, the tractive resistance is increased fast. The tractive resistance will be affected by both forward velocity and vibration frequency, but the effect for the tractive resistance by the former is small relatively. The research result provides the reference basis for the structure design of the agricultural mechanical system.

Keywords: *Material Acting Force, Vibrating Subsoiler, Kinetics, Forward Speed, Tractive Resistance.*

1. INTRODUCTION

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In recent years, researchers have done extensive work on vibration drag reduction. In mechanical engineering, Professor Wen Bangchun and his colleagues find, for internal friction, under vibration load, the internal friction coefficient of discrete particles changes considerably and its reduction rate is relatively higher; for external friction, vibration can decrease friction between objects and abrasion of parts can be avoided effectively which results in lower energy consumption and drastic higher work efficiency [1-5].

In agricultural mechanical engineering field, domestic and foreign researchers place their focus on R&D of vibration drag reduction in tillage equipment, including improvement of design and performance for tillage devices, relationship between vibration coefficient and tractive resistance, and stress analysis of tillage parts.

In tillage equipment design and performance improvement, Sahay and others have developed a new type, which, after its transmission system is modified, can supply 9-13Hz of vibration frequency and 15-35Hz vibration amplitude. Experiments show, the plowing depth of vibration tillage equipment is 15.3cm, while that of the same equipment without vibration is only 7.4cm [6]. Wu Guangwei and his colleagues designed a meadow vibration spacing scarifier, which shows stable work and effective scarification with advancing speed of 1m/s and vibration frequency of 10.0Hz [7]. Tong Hongxin adopted a deep scarification mechanism by combining small shovels with vibration, which produces vibration from reciprocating motion of plow shank by means of crankshaft, drastically reducing power consumption, decreasing traction resistance, ensuring soil particle size, intensifying deep scarification effects, and enhancing work quality[8].

In research on relationship between vibration coefficient and traction resistance, after considering traction resistance, power demand and driving comfort, Sakai and others developed deep vibration scarifier with four columns of deep plowing shovels. Experiment shows, under high vibration amplitude and low frequency, this equipment can reduce traction resistance and save energy consumption [9]. Slattery and colleagues compared non-vibration shallow shovels and vibration deep shovels, and concluded that, under working condition of 69mm amplitude and 278° of vibration angle, the latter showel can more effectively reduce traction resistance, energy consumption and increase soil loosing efficiency [10]. The University of South Australia developed a deep scarifying shovel, which has two columns of vibration shovels, and four shallow scarifying shovels can be added to intensify soil loosing efficiency. Repetitive experiments and researches find, when vibration frequency approaches 3.3Hz, tillage equipment needs the least power consumption, which is 26% lower than that without vibration [11]. Shahgoli and colleagues concludes, reduced vibration angle can decrease traction force; when vibration reduces from 8° to 1.5°, traction force decreases the most precipitously[12]. Niyamapa concludes by experiment and research, under vibration working conditions, the initial traction of tillage equipment will increase slightly as advancing speed goes up, but decrease consequently. When working without vibration, traction increases continuously as advancing spped goes up. The traction force ratio beween vibration mode to non-vibration mode changes from 0.63 to 0.93[13-14]. Li Yanlong invented a vibration deep scarifier based on leverage principle, whose comparason of traction resistance between vibration and non-vibration modes at the plowing depth of 30cm shows, vibration deep scarification can effectively reduce machine traction resistance by 13% to 18% [15]. Dong Xiangqian explored meadow soil breaking mechanism of scarification devices under forced vibration, which shows that when there is an angle between the scarifying parts and shoveling direction, vibration mode is helpful in loosing soil and reducing traction resistance of the device[16]. Zhao Daowei invented a vibration deep scarifier, which, when compared with common scarifier, can dramatically reduce the traction resistance of the whole machinery set, energy consumption and elevate deep loosing quality under similiar soil structure and working conditions[17].

In stress analysis of plowing parts, Zhou Yi linearized plowing resistance, and concluded by dynamic calculation and repetitive tests that vibration can effectively reduce soil specific resistance and plowing resistance [18]. Gebregziabher studied plowing parts by definite element analysis, the results of which show that, when traction angle is decreased, the device tangential stress is larger than that of vertical stress. When the traction angle is $\leq 30°$, compared with traditional calculation, definite element calculation results has an error <3% in traction, while that of vertical stress is 5% [19]. Shmulevich simulated the mutual interaction between soil and plowing parts by discrete element method, in which he studied stress analysis of the plowing parts with different shapes, and the results show that the shapes of plowing parts directly affect the amount of propelling force, among which straight blade plowing part can advance in soil with little transverse force[20-21].

In summary, due to the complexity and variety of plowing device resistance, most scholars at home and abroad adopt experimental methods to study vibration tillage equipment and have achieved meaningful conclusions [22-29]. In practice, vibration amplitude, frequency and direction have some influence on tillage equipment resistance. Reasonable application of these coefficients in design can effectively increase working efficiency of vibration deep scarification machines. This article puts forward a mechanical model of vibration deep scarifier by taking consideration of material action force, and by numerical integration solution and analysis, it finds the influence of vibration amplitude and frequency on system mechanical features and researches the relationship among the vibration frequency, the forward velocity of tractor and the tractive resistance by indoor soil bin test through 1SZ-160 tillage implement, and verify the correctness of the model.

Section 2 and 3 discuss vibrating subsoiler-soil system mechanics model establishment and simulation, and simulation data and results are analyzed in section 4. Test and method, analysis of test data of vibrating subsoiler-soil system are introduced respectively in section 5 and 6. Section 7 summarizes and concludes the paper.

2. VIBRATING SUBSOILER-SOIL SYSTEM MECHANICS MODEL STABLISHMENT

Figure 1 is the vibrating subsoiler-material system simplified model.

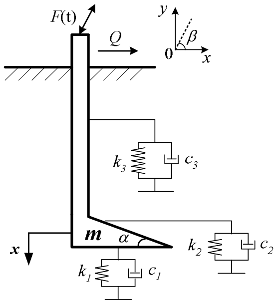


Figure.1 Vibrating Subsoiler-Soil System Simplified Model

Where m is the weight of the vibrating shovel, *k_1, k_2* , *k_3* are the material rigidity； *c_1, c_2* ,*c_3* are the damp rigidity； *F(t)* is the vibration force； β is the vibration direction angle； *x* is the vibrating shovel displacement.

This paper only considers the vertical direction motion of the system.

The system mechanics differential equation is as follows:

$$m\ddot{x}+\left(c_1+c_2\sin\alpha+c_3\right)\dot{x}+(k_1+k_2\sin\alpha+k_3)x = F\sin(\omega t+\varphi_1)\sin\beta \tag{1}$$

3. VIBRATING SUBSOILER-SOIL SYSTEM SIMULATION

This paper adopts four-stage Runge-Kutta method for numerical simulation study.

Basic system parameters are:

m=61kg, k1= (95184-184825) N/m, K2= (97893-243459) N/m, k3= (92132-15466) N/m, c1=(240-1140) N · s/m, c2=(82-390)N · s/m , c3=(93-440)N · s/m.

3.1 Amplitude's Effect on System Response

When the vibrating frequency is 12Hz, amplitudes are respectively 0.005m, 0.01m, 0.02m, 0.03m other parameters remain unchanged, the system time-displacement curves are as shown in the figure 2.

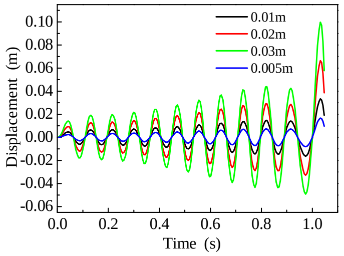


Figure.2 Time-Displacement Curve

3.2 Vibrating Frequency's Effect on System Response

When the amplitude is 0.01m, the frequencies are respectively 9Hz, 10Hz, 11Hz, and 12Hz, other parameters remain unchanged, the time-displacement curves of the system are as shown in figure 3 to figure 6.

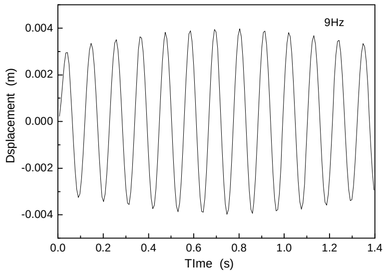


Figure.3Time-Displacementcurve

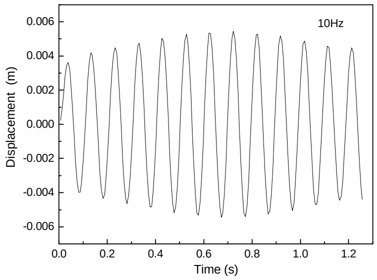


Figure.4Time-Displacement Curve

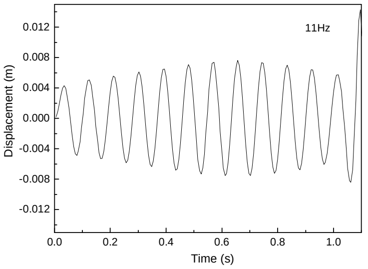


Figure.5Time-Displacementcurve

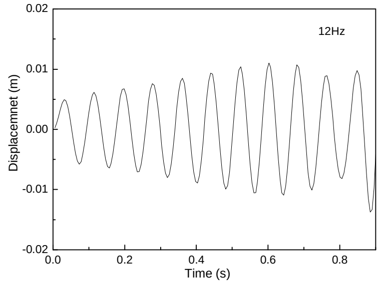


Figure.6Time-Displacement Curve

3.3 Vibrating Angle's Effect on System Response

When the amplitude is 0.01m, the frequency is 16Hz, and the vibrating angles are respectively 20°, 30°, 40°, and 70°, and other parameters remain unchanged, the system time-displacement and frequency-amplitude curves are as shown in figure 7 to figure 10.

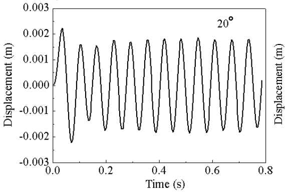


Fig.7Time-Displacementcurve

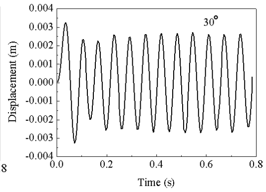


Fig.8Time-Displacement curve

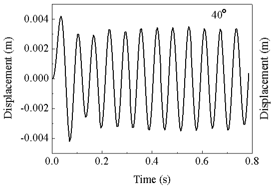


Fig.9Time-Displacementcurve

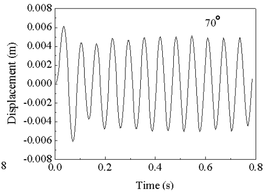


Fig.10Time-Displacement Curve

4. SIMULATION DATA ANALYSIS

(1) It can be known from figure 2 that, when the vibrating frequencies are the same, the system displacement curve change is similar: when t=1.1s, the lifting displacement of the vibrating shovel has sudden change; when the amplitude is comparatively large, the sudden change is obvious. Such working condition will accelerate the abrasion of the vibrating shovel and is not good for subsoiling work. Therefore, such working conditions shall be avoided.

(2) It can be known from figure 3 to figure 6 that, if the amplitudes are the same, when the frequency is 11Hz, the vibrating shovel lifting displacement has sudden change, and its vibrating range has comparatively large change; when the frequencies are respectively 9Hz and 10Hz, the motion rule of the vibrating shovel are similar, and the displacement change is comparatively stable, but the later one's vibrating range is larger than the former one; when the frequency is 12Hz, the vibrating shovel displacement change is comparatively large at the initial phase, but with vibrating goes on, the displacement becomes steady.

(3) It can be known from figure 7 to figure 10, when the amplitude and the frequency are the both the same, the vibrating angle's effect to the system displacement response is large. With the increase of the vibrating direction angle, the shovel's vibrating range increases too.

5. TEST AND METHOD

The test site is indoor soil bin in the laboratory building. The area of the soil bin is 2m*40m. According to different water contents and firmnesses of the soil, the test region is divided into 12 pieces.

5.1 Test Equipment

Red east-354 tractor is applied to the test. The test system comprises a self-regulating force measuring system, a vibration test system, a dynamic strain indictor, a soil water tester, a soil firmness tester and a rolling wheel. The physical qualities which shall be measured are the acceleration response of the driver's seat of the tractor and the tractive resistance, wherein the acceleration response reflects the vibration situation in the cab of the tractor. In the optimum vibration working condition, the vibration and tractive resistance in the cab are low.

In the farming process, the simulation signal is output to the front intelligent data collection end by the sensor. The data is processed to output the digital signal, the digital signal is input into the computer for treatment by USB and is converted into the data to be measured according to the calibration equation.

The piezoelectric sensor is placed in the cab. The signal is output by the piezoelectric sensor, and the acceleration data of the tractor cab is obtained after amplification, filtering, A/D conversion and data treatment of the signal by the vibration test system.

The self-regulating force measuring system is composed of the Π-shaped force measuring frame and three octagon ring sensors. According to different installation methods, the test of the tractive resistance and farming resistance can be completed by the system, respectively. When the octagon ring sensors are in three-point suspension connection with the tractor, the tractive resistance is tested by the force measuring system. When the octagon ring sensors are in three-point suspension connection with the tillage implement, the test object is the farming resistance. The tractor traction equipment is connected with the vibration subsoiler by the octagon ring sensors through the connecting pieces. In the forward process of the tractor, the resistance strain piece on the octagon ring sensor is deformed, the vibration is converted into the voltage signal by the dynamic resistance strain gauge, and the data of tractive resistance and farming resistance is obtained after data treatment.

5.2 Test Process

The test comprises two working conditions such as vibration and non-vibration, wherein for the test in the vibration working condition, the power output shaft of the tractor is connected with the spline shaft of the tillage implement by the cross flower universal joint. For the test in the non-vibration working condition, the tractor is also connected with the tillage implement by the force measuring system, but the power output shaft is not connected with the spline shaft of the tillage implement.

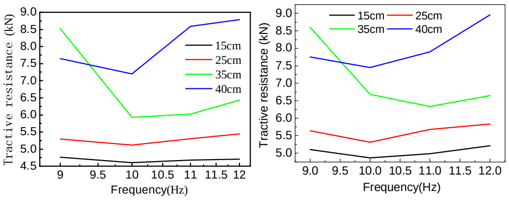
The forward velocity of the tractor is 0.2m/s, 0.3m/s and 0.49m/s respectively. The vibration frequency is 9Hz, 10Hz, 11Hz and 12Hz respectively. After the farming in each working condition, the soil is compressed by the compression roller, and the firmness of the soil is tested to be the same with the initial value, and the initial farming state of the soil is recovered, so that the accuracy of the test data is guaranteed.

6. ANALYSIS OF TEST DATA

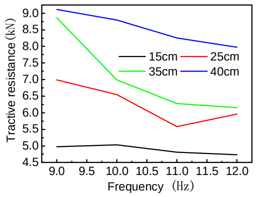
The vibration drag reduction test comprises 12 test working conditions, wherein the vibration frequency of 1 to 4 working conditions is 9Hz, 10Hz, 11Hz and 12Hz respectively, and the forward velocity is 0.2m/s; the vibration frequency of 5 to 8 working conditions are not changed, and the forward velocity is 0.3m/s; the vibration frequency of 9 to 12 working conditions are not changed, and the forward velocity is 0.49m/s.

6.1 Tractive Resistance and Cultivated Depth Data in the Various Working Conditions

The frequency, tractive resistance and cultivated depth data in the various working conditions are as the Figure 11.



(A) 1-4 Working Conditions(B) 5-8 Working Conditions



(C) 9-12 Working Conditions

Figure 11. Diagram For Frequency, Tractive Resistance And Cultivated Depth Data In The Various Working Conditions

(a) and (b) in the Figure 4 show that when the forward velocity is the same and the cultivated depth is 15cm and 25cm, the tractive resistance has similar change rules, the value is increased with the increase of the cultivated depth. When the vibration frequency is 10Hz, the value is small and the fluctuation range of the numerical value is small relatively. When the cultivated depth is 35cm and 40cm and the vibration frequency is 9Hz, the tractive resistance is reduced with the increase of the cultivated depth. When the cultivated depth is 35cm and the vibration frequency is 11Hz, the tractive resistance is low. When the cultivated depth is 40cm and the vibration frequency is 10Hz, the tractive resistance is low. The Figure (c) shows that when the forward velocity is high, the tractive resistance is reduced with the increase of the vibration frequency.

The comparison of (a), (b) with (c) in the Figure 4 shows that the forward velocity has some effects for the tractive resistance, and the tractive resistance is increased with the increase of the forward velocity.

6.2 Soil Firmness Data in the Identical Forward Velocity and Different Vibration Frequencies

The forward velocity is 0.2m/s, the vibration frequency is 9Hz, 10Hz, 11Hz and 12Hz respectively. The soil firmness data after deep scarification is as the Table 1.

6.3 Comparative Analysis of Data

According to the data in the Figure 11 and Table 1, when the forward speed is 0.2m/s and the vibration frequency is 10Hz, the effect of loosening the soil is good and the tractive resistance is low. The conclusion tallies with the simulation result.

Table 1 Soil Firmness Data In The Identical Forward Velocity And Different Vibration Frequencies

Frequency (Hz)	Soil firmness data before deep scarification (kg/cm^2)	Soil firmness data after deep scarification (kg/cm^2)
9	22.75	15.17
10	22.75	11.79
11	22.75	14.2
12	22.75	15.86

7. CONCLUSIONS

During the vibrating subsoiling process, the material acting force is the real reflection of the system kinetics features. This paper establishes the single degree of freedom model considering material acting force and proves the correctness of this model through comparison between the simulation data and practically measured data. The good working condition of 1SZ-160 tillage implement is as follows: the forward velocity is 0.2m/s and the vibration frequency is 10Hz, the tractive resistance is low and the effect of loosening the soil is good at this moment. On a certain cultivated depth position, the forward velocity has some effects for the tractive resistance, and the tractive resistance is increased with the increase of the forward velocity. When the tractor is forward fast, the tractive resistance is reduced with small amplitude in the vibration and non-vibration working condition.

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