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Experimental Study on the Dynamic Characteristics of Spring-Tooth Vibration Sub-Soiling Shovel

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ABSTRACT: In order to study the dynamic characteristics of spring-tooth vibration sub-soiling shovel in subsoiling process and its influences to subsoiling performance, this paper sets spring-tooth sub-soiling shovel and rigidityity sub-soiling shovel as study objects. Through soil test trolley ,vibration tester and other equipment and by applying mechanical vibration principle and signal testing technology, it has tested the vibration and traction of the two kinds of sub-soiling shovels. Through the contrast test and data processing it finds out that: the vibration of spring-tooth sub-soiling shovel belongs to random forced vibration. The main causes of its vibration is the constant changing of soil resistance. At the near surface area, compared with rigidityity sub-soiling shovel the traction resistance of spring-tooth sub-soiling shovel decreases by 9.95% and subsoiling specific resistance decreases by 14.52%, which offers a better resistance reduction effect.

KEYWORDS: Sub-Soiling shovel; Vibration; Spring tooth; Dynamic characteristics.

INTRODUCTION

Subsoiling technology is one of the core technology of soil conservation tillage, subsoiling breaks the plow pan and improves the soil permeability. The soil structure after subsoiling is not only conductive to nutrient release and storage but also to beneficial to the further development of the root system, providing the most suitable soil structure for crop growth. But if the plow pan is too thick or solid it will costs a lot of energy. Vibration resistance reduction is the most effective method among numerous measures. According to the the differences of vibration direction, vibration frequency and amplitude, after setting up a series of experiments, domestic scholars have designed many subsoilers and have achieved excellent experiment results [1-6]. Some foreign researchers have studied that different vibration parameters make traction and total power decrease. Their experiments have studied different designing factors of subsoiler, such as the shape of shovel tip, the shape of shovel shaft, the influence of different vibration parameters to traction and total power [7-11]. However, these subsoiling mechanism usually adopts eccentric wheel, cam or crank link mechanism to product vibration which is forced vibration, and compared with non-vibration subsoiler, even thought it can reduce traction it requires more power to break soil. Spring-tooth is a kind of non-typical and practical forced vibration part. When it is used for plowing, as the farm machine moves forward, the spring-tooth produces vibration under the effect of soil resistance, which doesn't need energy consumption at all [12]. Home and abroad,the study of spring-tooth is confined to theoretical study and few people had applied spring-tooth to subsoiling to do experimental study [13]. This paper through experiments to compare spring-tooth sub-soiling shovel's and rigidityity sbusoler 's influence to subsoiling performance, analyzes applicable conditions of the two kinds of sub-soiling shovels, and further studies vibration characteristics of spring-tooth sub-soiling shovel. Theoretical research combing with experiment, it provides theoretical basis for deeper study of subsoiler of various vibration modes.

MATERIAL AND METHOD

Composition of Instrument Equipment and Test System

Soil box test was conducted in agriculture machinery soil box test room of Liaoning agricultural mechanization research institute. The soil box of sandy loam soil is 30m in length, 2.95 in width and 0.4 din depth. The drive in the test is electric four-wheel drive experiment cart. The cart runs on rails. At the back of the experiment cart there is force test frame, and there are 6 pull-press sensors. Two of the senors are used to test the horizontal force of traction equipment, three are used to test vertical force an one is used to test lateral force. The main experiment instruments are: XL1101 strain type acceleration transducer, VIB2008 vibration tester, pc, spring-tooth sub-soiling shovel, rigidityity sub-soiling shovel, soil moisture tester and soil penetrometer.

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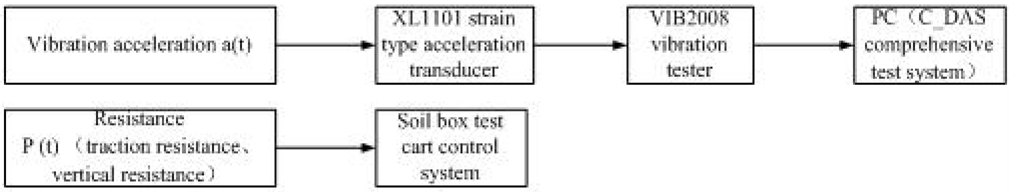
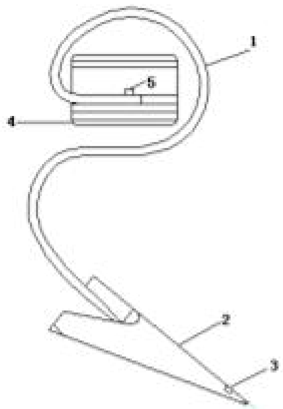
Vibration acceleration signal acquisition by strain type acceleration transducer converts the analog signal to digital signal. The vibration tester collects the digital signals to input it to computer and it is output by C_DAS comprehensive test system. Resistance signals are produced by sensors that used to test traction resistance and vertical resistance on force test frame and they are collected, displayed and stored by soil box test cart control system. As shown in Figure 1 a.



a. Components of test equipment



1. Spring-tooth sub-soiling shovel shaft 2. V-shaped sweep

3,5. Strain type acceleration transducer 4. Connection device

b. Connection diagram of test components and spring-tooth sub-soiling shovel

Figure 1. System composition of spring-tooth sub-soiling shovel shaft.

Experiment Method and Steps

Prepare test: the average soil moisture was 14.8% in the soil bin. The average soil firmness was 968 kpa at 30cm. The soil was calibrated with a grader in order to keep the same tillage depth.

Resistance test: by testing the traction resistance and vertical resistance, it can measure energy consumption of different sub-soiling shovels in subsoiling process and force distribution of sub-soiling shovel. Respectively install different spring-tooth sub-soiling shovels to force test frame at the back of the soil box cart, and through changing the advance speed of soil box cart and entering ground depth it analyzes the subsoiling performance of different subsoiling shafts, and then judges the applicable situations for different sub-soiling shovels.

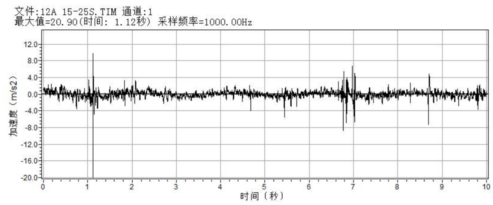
Vibration acceleration test: in the tillage process, due to the S shape of spring-tooth and soil resistance, the swing and vibration is maximal at spring-tooth tip. To study the vibration characteristics of spring-tooth sub-soiling shovel, strain type acceleration transducer is installed at the spring-tooth tip (channel 1), in addition, acceleration sensor (channel 2) is placed at the connection part of spring-tooth and force test frame to test the vibration transferred from soil box cart to spring-tooth. As shown in figure 1b. By changing subsoiling and plowing speed it conducts resistance test and vibration acceleration at the same time to find out the connection between them.

RESULT AND ANALYSIS

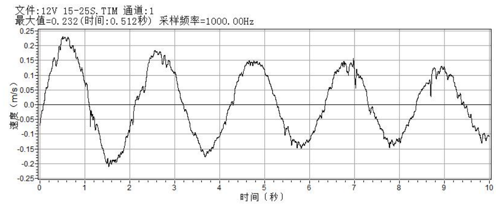
Vibration Characteristics Analysis

Vibration Process Analysis

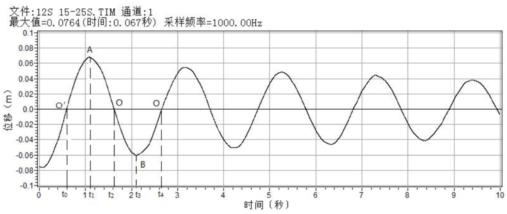
With ploughing depth 20cm and ploughing speed 0.3m/s, it conducts spring-tooth vibration acceleration test and resistance test. Because there will be an impact effect when the soil box cart starts and stops which will influence test results, it only cut out 10s stable process. The time history of vibration acceleration of spring-tooth tip is shown as figure 2a. It can find out from figure 2a that the vibration of spring-tooth sub-soiling shovel is random. The reason is that soil resistance works on spring-tooth sub-soiling shovel and the soil heterogeneity causes its vibration, so the vibration at the spring-tooth tip changes as the soil resistance changes. Acceleration a (t) integration for once can get velocity v(t), and velocity signal integration for once can get displacement. Therefore each integral it should conduct high-pass filtering, the filter frequency is from 0.5Hz to 500Hz. Vibration acceleration waveform after two times of integral and three times of high-pass filtering, the vibration displacement waveform is obtained. From the vibration time history profile(figure 2c) it finds out that the maximal vibration speed of spring-tooth is 0.2m/s which is smaller than the ploughing speed of sub-soiling shovel. From the vibration displacement time curve we can find out that the vibration cycle of spring-tooth is 2s.



a. Time history of vibration acceleration



b. Time history of vibration speed



c. Time history of vibration displacement

Figure 2. Dynamic response curve of spring-tooth sub-soiling shovel tip.

Figure 3 shows the deformation condition of spring-tooth during plowing. As the machine moves forward,in t0-t1 period, the spring-tooth tip of the sub-soiling shovel moves from O′ point to A point, the elastic potential energy gradually increases from zero and the elasticity is less than the soil resistance. When the spring-tooth tip reaches the maximal deformation point, point A, that is, it reaches t1, the elastic potential energy of spring-tooth is largest. In t1-t2 period, the spring-tooth springs back and release energy. At this point the soil resistance reaches yield limit and the soil is loosed. When the spring-tooth goes back to its equilibrium position (O point), that is t2, the elastic potential energy is O and sub-soiling shovel‘s impact to soil is O. In t2-t3 period, the sub-soiling shovel continues to move forward and compresses loose soil, so the soil resistance keeps increase and the spring deforms to the other direction and saves energy. When it reaches maximal deformation point B, the elastic force is largest and gives out energy, then it goes back to equilibrium point (O point, t3-t4 period)and repeats the above process. The plowing process of spring-tooth sub-soiling shovel can concluded as: soil resistance increasing leads to spring-tooth deformation and storing up energy. When the elastic potential energy of spring-tooth is largest and reaches the soil yield limit it rapidly releases energy. Therefore, the changing of soil resistance is the main cause of the vibration of spring-tooth sub-soiling shovel.

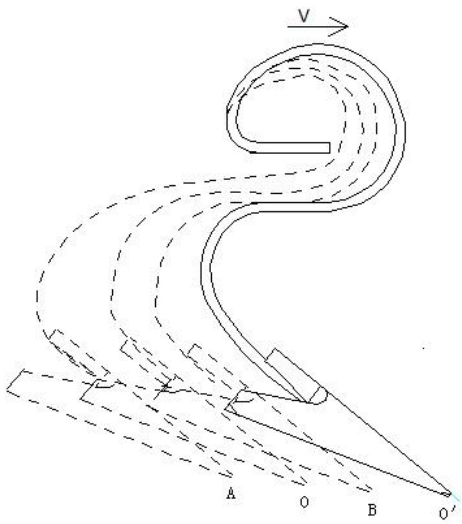
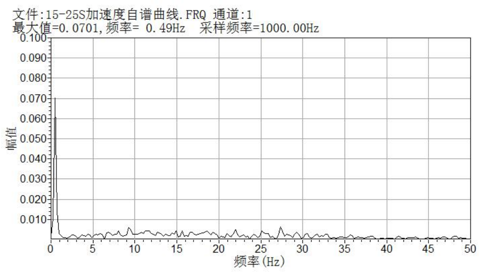


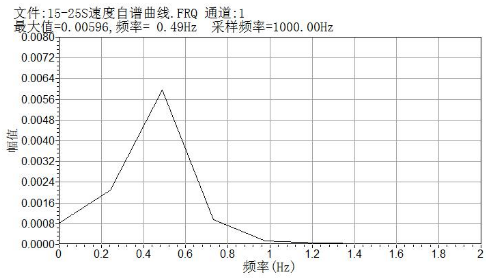
Figure 3. Plowing position of spring-tooth.

Power spectral density analysis

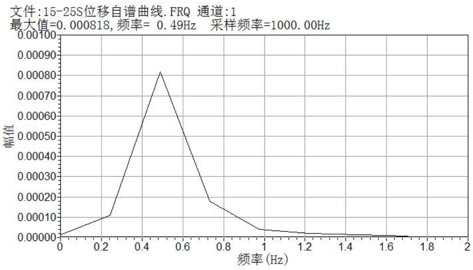
Power spectral density function is the main statistical parameter of random vibration frequency characteristics, which can be used to show the average spectrum characteristics of random vibration. Auto-power spectral density function demonstrates the distribution of power of vibration signal's frequency and makes us know that whose power frequency is dominating [14]. Figure 4 shows the dynamic response power spectral density curve of the tip of the spring-tooth subsolier. It can be found from the figure that when vibrational frequency reaches 0.49Hz, vibration acceleration, vibration velocity and vibration displacement can all acquire their maximum values and they are 0.07m/s,0.006m/s and 0.0008m/s respectively, which illustrates that random signal mainly centers on this very frequency. Therefore, we can safely draw the conclusion that the main vibration frequency of spring-tooth sub-soiling shovel is when the vibration main frequency of elastic claw deep and loose relieved tooth gets 0.49Hz, the frequency is 0.49Hz and relatively low, which explains that some low frequency constituents, such as the uneven earth surface and the asymmetry soil texture lead to the constant change of the soil resistance, furthermore cause the vibration of spring-tooth sub-soiling shovel.



a. Frequency-amplitude curve of vibration acceleration autopower spectrum



b. Frequency-amplitude curve of vibration speed atuopower spectrum



c. Frequency-amplitude curve of vibration displacement atuopower spectrum

Figure 4. Dynamic response power spectral density curve of spring-tooth sub-soiling shovel tip.

Analysis of Traction Resistance

From Figure 5 traction resistance dynamic response curves of spring-tooth sub-soiling shovel and rigidity sub-soiling shovel, it can be obviously seen that the rigidity sub-soiling shovel's traction resistance is stronger than that of the spring-tooth sub-soiling shovel's in overall trend. From the comparative results of the effects of spring tooth and rigidity tooth on subsoiling performance (Table1.), it can also be known that when the forward speed and operating depth are the same, the traction resistance of spring tooth decreases by 9.96%, the standard deviation falls from 38.52 to 30.22, the coefficient of variation goes down from 0.077 to 0.067 in contrast with rigidity tooth, which shows that the spring tooth has better resistance reduction effect. The working stability is also improved. In contrast with the rigidity tooth, the vertical force of spring tooth reduces by 94.42%, the standard deviation falls from 43.43 to 31.18, which demonstrates that the spring tooth have lower resistance that the rigidity tooth in vertical direction. However, the coefficient of variation increases from 0.051 to 0.659, because the spring tooth get deformed and release elastic energy when meet soil resistance, thus resulting in a large range of disturbance in the vertical direction. The total force of spring tooth acting on soil and the horizontal angle is greater than that of rigidity tooth, which also proves that the spring tooth have a stronger acting force in the vertical direction. From the soil failure effect, we can know that the spring tooth has a larger range of soil disturbance and the sub-soiling specific resistance decreases by 14.52%. Therefore, the spring tooth has better sub-soiling effect than the rigidity tooth.

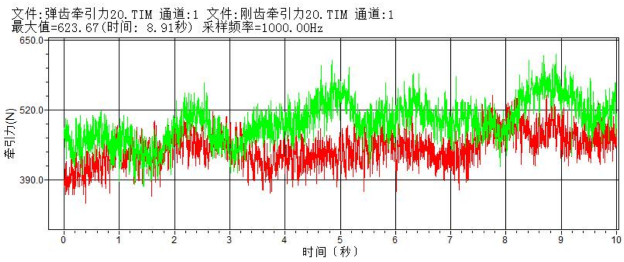


Figure 5. Traction resistance dynamic response curves of spring toothed sub-soiling shovel and rigidity sub-soiling shovel. (Red curve: spring toothed sub-soiling shovelGreen curve: rigidity sub-soiling shovel)

Table 1. Effects of spring toothed sub-soiling shovel and rigidity sub-soiling shovel on subsoiling performance.

		Spring-tooth sub-soiling shovel	Rigidity sub-soiling shovel
Forward speed[m/s]		0.3	0.3
Operating depth[cm]		20	20
Traction resistance[N]	Average	449.03	498.65
	Maximum	547.33	623.672
	Minimum	346.92	378.476
	Standard deviation	30.22	38.52
	Coefficient of vibration	0.067	0.077
Vertical force[N]	Average	47.28	847.54
	Maximum	260.484	996.758

	Minimum	-110.642	0
	Standard deviation	31.18	43.43
	Coefficient of vibration	0.659	0.051
Resistance and horizontal angle[°]		83.99	30.47
Soil failure area[cm2]		423	400
Sub-soiling specific resistance [N/cm2]		1.06	1.24

Niyamapa and Salokhe found that characteristics of soil disturbance could be divided into two main areas, namely the deep area and near-surface area in study of the sand soil destruction and soil disturbance. The soil breaks into small fragments in deep area and large colds in the near-surface area [15]. The soil plow pan is located at about 20cm below the surface. Its stiffness is about three times thicker than the top soil [16]. The purpose of sub-soiling is to break the plow pan and loosen soil. The above analysis shows that the spring-tooth vibration is unstable in the vertical direction and the released elastic energy is not sufficient to loosen the plow soil, so the spring-tooth sub-soiling shovel is more suitable to loosen the top soil. Therefore, the spring-tooth sub-soiling shovel can first be used to break the soil in the near-surface area, namely 0~20cm below the surface, while the rigidity sub-soiling shovel can be applied for deep soil loosening in the deep area, namely more than 20cm below the surface.

CONCLUSIONS

1) The changes of soil resistance leads to the vibration of spring-tooth sub-soiling shovel. When the soil resistance gets stronger, the amount of spring tooth deformation will increase. Once the spring-tooth elastic force reaches the maximum and is beyond the soil bearing limit, it will quickly rebound and release energy to loosen soil. Then the soil resistance becomes smaller, the spring tooth move forward in the loose soil. The elastic energy will get accumulated again when the spring tooth meet the tight soil. Such process repeats like this to generate continuous vibration.

2) The vibration frequency of spring-tooth sub-soiling shovel is only 0.49Hz which is relatively low. It shows that such low-frequency components as uneven rough surface and nonuniform soil cause the changes of the soil resistance, further illustrating that the spring-tooth vibration belongs to the random forced vibration.

3) When the forward speed and operating depth are the same, the traction resistance of spring-tooth sub-soiling shovel drops by 9.95% in contrast with the rigidity sub-soiling shovel. The sub-soiling specific resistance also decreases by 14.52%. So the spring-tooth sub-soiling shovel has a better resistance reduction effect.

4) The spring-tooth sub-soiling shovel is suitable for near-surface area while the rigidity sub-soiling shovel is better for plow hard soil, namely more than 20cm below the surface.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

ACKNOWLEDGEMENTS

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