IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Design and Analysis of Bionic Rib Subsoiling Shovel Based on Hawaiian Shell

To cite this article: Feng Tiantao *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **267** 032048

Design and Analysis of Bionic Rib Subsoiling Shovel Based on Hawaiian Shell

Feng Tiantao[1, 2], Xu Lingfeng[1, 2, *], Song Yuepeng[1, 2], Li Fade[1, 2] and Song Zhanhua[1, 2]

[1]College of Mechanical and Electrical Engineering, Shandong Agricultural University, Tai'an 271018, China

[2]Shandong Provincial Key Laboratory of Horticultural Machinery and Equipment, Tai'an 271018, China

[*]E-mail：lingfengxu@126.com（Corresponding author）

Abstract: In order to reduce the tillage resistance in the subsoiling process of soil, this paper uses a three-dimensional laser scanner to obtain the data point cloud on the outer surface of Hawaiian shellfish, and performs curve fitting, and designs 14 bionic ribbed subsoilers with different shapes according to the fitting function. In order to analyze the drag reduction effect of various subsoiling shovels, the average tillage resistance of 14 bionic subsoiling shovels and non-bionic subsoiling shovels with smooth surfaces was calculated. The results show that the tillage resistance of bionic subsoiling shovels is less than that of non-bionic subsoiling shovels, the drag reduction effect of 45 degrees rib angle is better than 30 degrees and 60 degrees, the drag reduction effect is better when the rib width is 30mm, and the number of ribs has no obvious difference.

1. Introduction

In the promotion process of subsoiling plough, excessive resistance is an important factor restricting its development. Seeking ways and means to reduce subsoiling tillage resistance is an important research content of agricultural machinery scientists in recent years, among which bionic design based on the structural characteristics of biological surface is a research hotspot, and scientists have conducted a large number of studies [1-6].

Shellfish living in the ocean have long experienced the abrasion of waves and sand, but they have shown good hydrophobicity and abrasion resistance. The reason is the materials of abrasion-resistant tissues and organs, and the microscopic or macroscopic geometric structure of organ surface. From the perspective of bionics, this paper takes Hawaiian shellfish as the research object, explores its geometric characteristics, and applies its wear-resistant and resistance-reducing mechanism to the structural design of subsoiling shovel, to study a bionic ribbed subsoiling shovel, in order to reduce the problem of excessive tillage resistance during soil subsoiling.

2. Bionic Object Information Extraction

The Hawaiian shellfish used were collected from Yantai, Shandong province, as shown in Fig.1. They were washed with distilled water and then air-dried. The three-dimensional laser scanner for acquiring the data of Hawaii shellfish outer surface is shown in Fig.2. Laser scanning is to hit a laser beam onto the surface of an object and receive reflected light from the surface of the object through a photosensitive device, thus calculating the coordinates of each point on the surface of the object. Therefore, more complicated structures such as ridges on the shell surface can be accurately obtained by this method. The scanning accuracy of the instrument used in this paper is 0.05mm within the range of 100mm depth of field. During measurement, the convex surface of a single Hawaiian shell is laid flat on the measuring table, and system parameters are selected for scanning measurement to obtain the data point cloud of the outer surface of the Hawaiian shell, as shown in Fig.3.

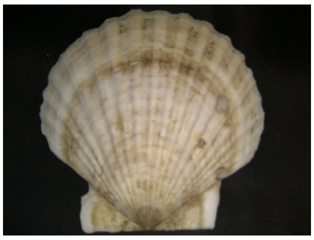

Fig.1 Hawaii seashell

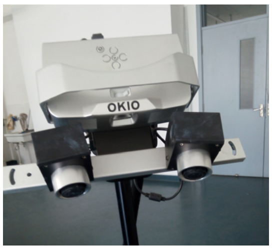

Fig.2 Laser scanner

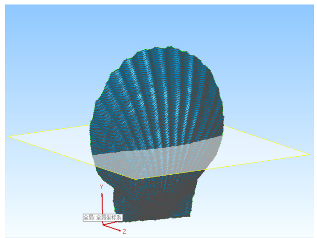

Fig.3 Data cloud

3. Curve Fitting of Characteristic Section

Point cloud data obtained by scanning are imported into Geomagic Studio software for packaging, and cross-sectional curves perpendicular to the positive direction of coordinate axes are respectively obtained. Comparative observation shows that the cross-sectional curves perpendicular to the Y-axis direction can best reflect the ridge convex features of Hawaiian shellfish. Therefore, this characteristic cross-sectional curve is imported into Origin 8.0 software to read the coordinates of points as shown in Fig.4, and curve fitting is performed as shown in Fig.5. The fitting equation is:

$$y = 56.1 + 10.1\sin[(x - 66.8)\pi / 87.8]$$

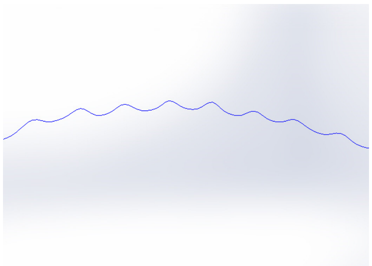

Fig.4 Characteristic section curve

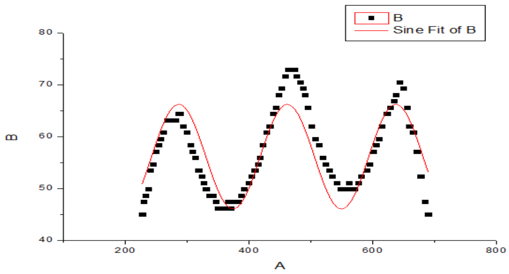

Fig.5 Characteristic points and fitted curve

4. Design of Bionic Subsoiling Shovel

4.1. Selection of Prototype of Bionic Subsoiling Shovel

Bionic subsoiling shovel is a bionic design based on the traditional smooth subsoiling shovel. The common subsoiling shovel tips are chisel-shaped, duck-palm-shaped and double-wing-shaped. Its shovel handle is relatively narrow. In order to ensure the distribution effect of bionic ribs, this paper selects Rakem Karat 9 subsoiling shovel as the prototype to design the bionic subsoiling shovel.

4.2. Determination of Bionic Rib Structure

According to the fitting equation, the cross-section line of the ridge on the outer surface of Hawaiian shellfish belongs to a chord function. SolidWorks software is used to apply its function characteristics to the ridge design of bionic subsoiling shovel. Combined with the movement form of soil ridges, the ridge is optimized to a structure gradually thickened along the rising direction of soil ridges, and each ridge is in a "V" shape with left and right symmetry.

IOP Conf. Series: Earth and Environmental Science **267** (2019) 032048 doi:10.1088/1755-1315/267/3/032048

4.3. Determination of Distribution Mode of Bionic Ribs on Subsoiling Shovel

The included angles between the ribs and the horizontal direction are designed to be 30 degrees, 45 degrees and 60 degrees respectively, the widths are 20mm, 30mm and 40mm, and the number of ribs is 4, 5 and 6 respectively. Considering the width of the subsoiler and the length of the arc section, the coefficient of the characteristic curve is modified appropriately, and 14 bionic subsoilers based on Hawaiian shellfish are designed, which are respectively marked as 30204, 30205, 45204, 45205, 45304, 45305, 60204, 60205, 60206, 60304, 60305, 60306, 60404, 60405, wherein, the first and second digits represent the "V" shaped rib inclination angle, the third and fourth digits represent the rib width, and the fifth digit represents the rib number. For convenience, the subsoiling shovel is marked with Arabic numerals 2-15 and the smooth surface subsoiling shovel without rib is marked with No.1 for comparison. The three-dimensional model of 15 subsoilers is shown in Fig.6.

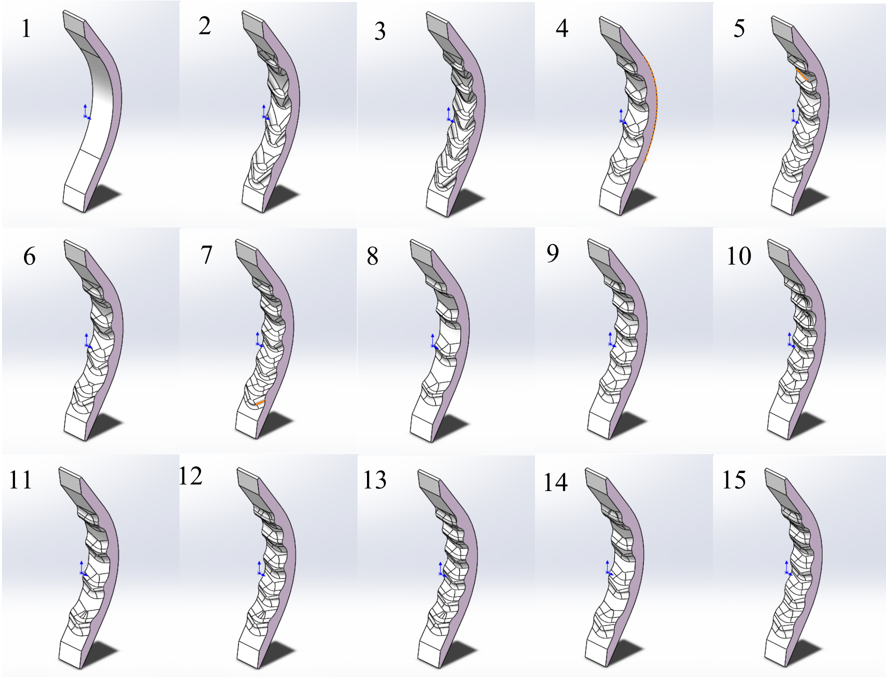

Fig.6 3-D models of subsoiler

5. Drag reduction effect analysis

5.1. Analysis of Average Tillage Resistance

The three-dimensional models of 15 sub-soiling shovels are respectively imported into the software for simulation, the simulation time is 1s, the graph lines of the tillage resistance of the sub-soiling shovels with time are respectively output in the post - processor, and then the tillage resistance when the sub-soiling shovels stabilize tillage is selected as the research object for data integration, Fig.7 is the resistance of different types of shovels at 0.4s, and it can be seen from the graph that the tillage resistance of the No. 1 sub-soiling shovel (i.e., 0000 type smooth surface sub-soiling shovel) is the largest, which is larger than that of all other types of bionic sub-soiling shovels, indicating that the bionic sub-soiling shovel is subjected to certain other factors. Among bionic subsoiling shovel, 45305 type subsoiling shovel has the least resistance, while 30204 type subsoiling shovel has the average tillage resistance. From the angle of inclination of "V" shaped ribs, the drag reduction effect at 45 is obviously better than that at 30 and 60, and the drag reduction effect at 60 is the worst, and it is not affected by the width and number of ribs. This may be because at 60, the inclination angle of "V" shaped ribs is too large, and the ribs are close to the horizontal, which is not conducive to the drag reduction during the rising process of soil embankment, while at 30, the "V" shape is pointed, which is helpful to break ground, but also increases the friction contact time between soil particles and shovel.

Judging from the width of "V" shaped ribs, the best drag reduction effect is when the width is 30mm, while when the width is too narrow, the ribs have no obvious disturbance to soil particles, reducing the rolling time of soil particles on the ribs, so the sliding time of particles is relatively prolonged, thus the friction between shovel and particles is relatively increased, while when the width is too wide, the friction contact time is relatively prolonged, which is not conducive to drag reduction. Judging from the number of "V" ribs, there is no obvious difference in drag reduction effect.

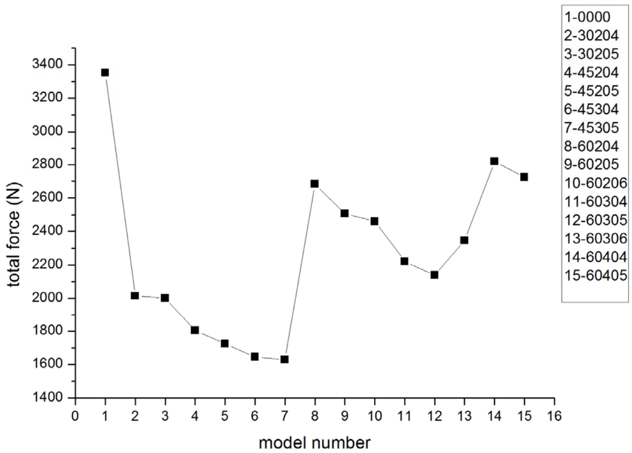

Fig.7 Average total force of subsoiler models

5.2. Analysis of Force Cloud Images

Taking the subsoiling shovel as the research object, as shown in Fig.8, the stress nephogram of 0000 model, 30204 model and 45305 model subsoiling shovel at 0.4s respectively, the color represents the stress of the subsoiling shovel, the red represents the maximum stress, the green takes second place, and the blue is the minimum. As can be seen from the figure, the red area surface of the top part of model 0000 subsoiling shovel is obviously larger than that of model 30204 and model 45305 bionic subsoiling shovels. The red area of the latter two bionic subsoiling shovels is small and scattered, and the green area of model 45305 subsoiling shovel is smaller than that of model 30204. During the simulation process, model 45305 subsoiling shovel has the best drag reduction effect when the surface is stably tilled.

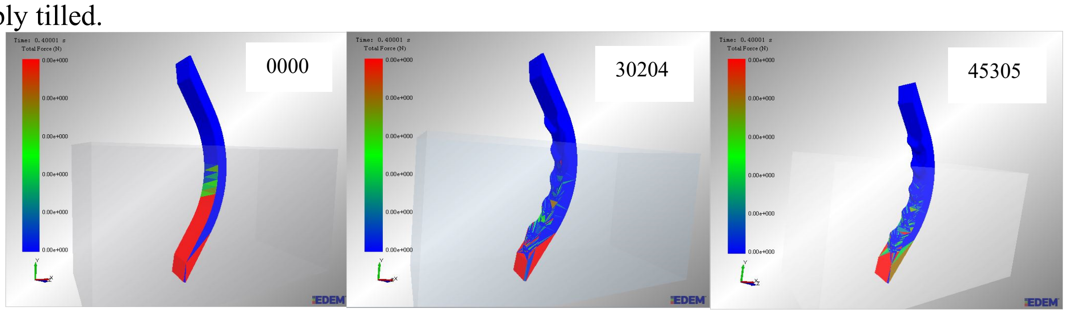

Fig. 8 stress nephogram of subsoiling shovel

Taking the soil model as the research object, as shown in Fig.9, the nephogram of normal force on the soil model at 0.4 second for 0000 model, 30204 model and 45305 model subsoiler respectively, the color represents the force on the soil model, with red bearing the largest force, green bearing the second and blue bearing the smallest. As can be seen from the figure, when the cultivation is stable, the red area and green area of 0000 model soil particles are slightly larger than those of 30204 model and 45305 model bionic subsoiling shovel, indicating that the normal force of 0000 model soil model is larger than that of the other two models bionic subsoiling shovel as a whole.

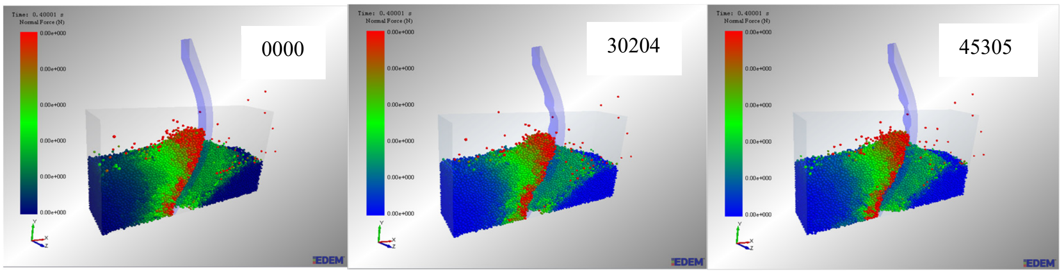

Fig. 9 Stress nephogram of soil model normal force

6. Conclusions

1) Three-dimensional laser scanning and curve fitting of characteristic section are carried out on the outer surface of Hawaii shellfish, and the fitting equation is as follows:

$$y = 56.1 + 10.1\sin[(x - 66.8)\pi / 87.8]$$

2) Bionic subsoilers with different combinations of ridge width, inclination angle and ridge number are designed according to the geometric size of subsoilers and the movement rule of soil embankment.

3) The smooth subsoiling shovel is more resistant to tillage than all other bionic subsoiling shovels. Among the bionic subsoiling shovels, 45305 has the least resistance, 30204 has the average resistance, and the rib drag reduction effect at 45 is obviously better than that at 30 and 60, and the rib width is 30mm, and the drag reduction effect is the best, with no obvious difference in rib number..

Acknowledgement

The authors would like to thank the National Key R&D Program of China (2018YFD0700604 and 2016YFD0701701), Shandong Province Natural Science Foundation (ZR2018MC017), Shandong Forestry Science and Technology Innovation Team Project (LYCX04-2018-22), and Shandong Agricultural University "Double-Class" Technology Innovation Team (SYL2017XTTD07) for the financial support.

References

[1] Li Jianqiao, Ren Luquan, Liu Chaozong, etc. A study on the bionic plow reducing soil adhesion and plowing resistance [J]. Transactions of The Chinese Society of Agricultural Machinery, 1996, 27(2): 1-4.
[2] Zhu Fengwu.Analysis of the Morphology of Scarabaeoidea and Bionic Design of Subsoiling Components [D].Changchun, Jilin University, 2005.
[3] Zhang Jinbo.Bionic Drag Reduction and Wear-resistant Theory and Techniques of Subsoile [D]. Changchun, Jilin University, 2014.
[4] Liu Runjie. Bionic Technology in Deep Scarification on The Drag Reduction Technology Research And Application [D]. Baoding, Hebei Agricultural Universituy, 2015.
[5] Deng Jiayu, Hu Jun, Li Qingda, etc. Simulation and experimental study on the subsoiler based on EDEM discrete element method [J]. Journal of Chinese Agricultural Mechanization, 2016, 37(4):14-18.
[6] Kou Bingxue. Resistance Reduction by Bionic Coupling of the Earthworm Lubrication Function[D]. Changchun, Jilin University, 2011.