Study on the opening soil knife cutting soil process of 3PF-240 small grape covering machine

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Abstract: Grape covering machine as key equipment casing mechanised grape winter is drawing more and more attention. To analyse the performance of the grape covering machine, the soil cutting process of opening soil knife with a 3PF-240 grape covering machine is studied. Based on the finite-element analysis software ABAQUS, the three-dimensional dynamic contact non-linear finite-element analysis of the soil cutting process was carried out, and the cutting force curve of the cutting tool in the case of the tool was obtained. To verify the correctness of the simulation results, the grounding work of the prototype was carried out. The experimental results show that the established mechanical model of the opening soil knife is correct, which provides a theoretical basis for the further development and optimisation design of the grape cover.

1 Introduction

Grape is an important economic crop in China as its overwintering technology is a key part of the whole production process. The quality and efficiency of the vine will directly affect the production of grapes. At the same time, the mechanisation of the grape overwintering vine technology has become an urgent problem for grape production. Scholars at home and abroad have done a lot of experiments and research work on grape covering machine, and have made great progress in the quality and efficiency of grape burial. However, there is much less research on the motion simulation analysis of small grape covering machine. During the operation of the small grape covering machine, the opening soil knife is a key component. The failure of the opening soil knife will directly lead to leakage, which will result in uneven soil covering and low quality of operation.

With the rapid development of finite-element technology and the continuous improvement of failure model and constitutive model, numerical simulation is occupying an increasingly important position in engineering design and analysis optimisation by virtue of its superior convenience and economy. The process of cutting the soil by the soil cutter of the grape covering machine is a non-linear dynamic problem, while the ABAQUS software is usually used for explicit non-linear dynamic analysis [1–3]. Therefore, this paper takes 3PF-240 small grape covering machine as the research object, uses the explicit module in ABAQUS to simulate the soil cutting of the opening soil knife of the grape covering machine, analyses the change of the cutting force during the cutting operation of theripper, and verifies whether the design of the opening soil knife can meet the working performance, and provides a theoretical basis for the development of high-performance new grape covering machine.

2 Structure and working process of the grape covering machine

The operation process of the grape covering machine mainly includes three links: soil cutting, soil breaking, and soil dropping, and its operation mode is similar to the rotary tiller. The high-speed rotation of the opening soil knife enables the cutting and throwing, and at the same time, the high-speed rotation makes the thrown clod to have a large line speed for achieving better soil-breaking effect and under the traction of the tractor, and it can guarantee a certain amount of soil movement, so the work efficiency will be greatly improved.

The soil-covering operation of the grape covering machine is realised by the rotation and forward composite movement of the opening soil knife, and its structure is shown in Fig. 1. It consists mainly of four parts: the frame, the transmission, the gearbox, and the knife seat. The frame is a three-point suspension type, and the transmission device adopts a belt transmission with the relatively smooth transmission, the knife seat portion is uniformly staggered on the cutter plate by the opening soil knife and the removing soil knife [4–6].

When the grape covering machine is working, it is towed by the tractor. The power is transmitted to the input shaft through the belt transmission mechanism by the way of the output shaft of the tractor. After the gearbox decelerates, it is transferred to the shaft of the holder of the knife, and the holder of the knife starts to work. At work, the composite movement of the opening soil knives carries out the soil and evenly throws the ground soil over the cover of the grape bed surface to complete the soil covering operation.

3 Theory model of the cutting soil

The main components of the knife wheel are shown in Fig. 2. Six opening soil knives and six removing soil knives are evenly distributed along the circumferential direction on the cutter wheel on the earth-cutter wheel at 45°.

3.1 Force model of the cutting soil

The interaction between the opening soil knife and the cutting soil conforms to the Rankine passive earth pressure theory, that is the soil in front of the opening soil knife will be subjected to passive
earth pressure. Based on the Rankine passive earth pressure theory, the cutting resistance model of the tilling tool established by Mcbes–Ali as a basis is taken. This paper establishes a force model of straight cutting soil by taking into account the effect of vertical thrust force and friction force when cutting soil with opening soil knife of grape covering machine.

In the process of burying the vine, the force acting on the soil has the cutting force, shearing force, lifting force, and friction on the cutting edge of the opening soil knife. The sum of the horizontal components of these forces constitutes traction resistance. The cutting force can be divided into two types according to the direction of vibration: one is the horizontal cutting force along the cutting direction, and the other is the vertical cutting force or the vertical propulsion force perpendicular to the cutting direction.

The force analysis of the opening soil knife is shown in Fig. 3. According to the working principle of the grape covering machine mentioned above and considering the calculation speed of the cutting simulation process, this paper simplifies the soil-cutting process model as a single opening soil knife rotating around the wheel axis of the soil-covering cutter as shown in Fig. 6, and takes the cutting depth of 50 mm.

4.1 Simplification of the model of cutting soil process

According to the working principle of the grape covering machine mentioned above and considering the calculation speed of the cutting simulation process, this paper simplifies the soil-cutting process model as a single opening soil knife rotating around the wheel axis of the soil-covering cutter as shown in Fig. 6, and takes the cutting depth of 50 mm.
4.2 Finite-element simulation of cutting soil process

In the process of cutting soil with six opening soil knives, a new surface is formed on the soil with one opening soil knife, so that the latter knife will continue to cut the new surface with the straight-line speed of the tractor output. It is reflected in the simulation calculation that the latter cutter contacts with the new soil surface and the contact analysis needs to be carried out again by the finite-element software. In the simplified model, although there is only one opening soil knife, the knife also contacts the new surface from the second circle, so the accuracy of the simulation results is not reduced.

In Pro/E, the model of opening soil knife is stored in IGES format, and then imported into ABAQUS. Since the structure of the soil is relatively simple, the modelling process is completed in ABAQUS/CAE, and the model of soil cutting by opening soil knife is shown in Fig. 7.

In the analysis, the soil is modelled as a Drucker–Prager constitutive model and the Drucker–Prager hardening type shear, and the setting of parameters is shown in Tables 1 and 2 [7–10].

This paper mainly simulates the process of cutting soil with the opening soil knife of the grape covering machine, so it is assumed that the soil cutting knife is a rigid body [11–14]. In ABAQUS, there is no need to assign rigid material properties or to participate in all cell-based calculations. In the non-linear contact analysis, when the main surface of the contact pair is the surface of the rigid body, the analysis is easier to converge, which will greatly improve the computational efficiency. The soil is a three-dimensional eight-node hexahedral linear reduction integral solid element-C3D8 [15–17]. So there is no need to select the unit type and meshing because of the opening soil knife is a rigid body [11–14].

4.3 Analysis of simulation results of soil cutting by opening soil knife

The results of equivalent forces of soil cutting by the opening soil knife are shown in Fig. 8. It can be seen from the figures that when the knife cuts into the soil, the soil area which first contacted the rake face of the knife will be directly squeezed, and the corresponding stress will be larger at this time. With the continuous advance of the opening soil knife, the areas of action between soil and the rake face of the opening soil knife are also increasing, the area of stress and deformation of soil will increase, and the maximum stress area will increase. When the stress value of a soil unit reaches the material failure value set before, the stress value will not increase but will decrease. This part of the soil will be separated from the original soil under the driving of the opening soil knife, and eventually be taken out of the soil model, which realises the stripping of the soil, realises the design requirements of the opening soil knife, and proves that the simulation process is in line with the actual excavation process of the cutter.

The traction of soil varies over time as shown in Fig. 9. It can be seen from the figure that the opening soil knives have a large impact force when they first come into contact with the soil, and...
5 Experimental study on cutting soil by opening soil knife

The experimental study on the model 3PF-240 grape covering machine shows that the covering operation is shown in Fig. 10. To achieve the expected effect of covering soil, the average cutting force required is 2.5–14.32 times the weight of the soil itself. According to the parameters of covering pitch $S$, knife width $B$, and soil bulk density, it can be estimated that the force required by the knife in the operation process is about $82.4–110\, \text{N}$, which is converted to $8.277 \times 10^4$ to $1.105 \times 10^5\, \text{Pa}$. The results are in good agreement with the numerical simulation of the maximum stress of $1.031 \times 10^5\, \text{Pa}$, as shown in Fig. 8b.

A comparative analysis of the results of soil cutting by a soil cutter is shown in Fig. 11. It can be seen from the figure that the experimental results are larger than the simulation results, and the overall deviation is about 13.4%. The reason for this result is that the cohesion between soil and tool is considered comprehensively in the test process, but in the simulation analysis, the cohesion between tool and soil is neglected because the tool has been set as a rigid body. Finally, the horizontal cutting force and vertical thrust force in the test are larger than the simulation results.

In conclusion, when the cohesion of the soil working environment of the grape covering machine is large, the cutting angle of the opening soil knife can be increased appropriately to...
achieve the desired effect of covering soil and ensure a certain power of covering the soil. It is also possible to replace different cutting knives according to different soil environments to increase the adaptability of grape mulching machines.

6 Conclusion

(i) According to the theory of ultimate bearing capacity when a rigid body invades the soil, the force model of soil cutting with the opening soil knife is established, and the formulas for calculating the vertical and horizontal cutting forces of soil cutting with opening soil knife are obtained.
(ii) Based on ABAQUS software, the three-dimensional dynamic contact non-linear finite-element analysis of the cutting process of the opening soil knife is carried out, and the stress nephogram and the traction curve of the soil during the simulation process of the cutting process of the opening soil knife are obtained. The relationship between the cutting force variation characteristics of the soil cutter and its structural parameters and soil properties is analysed. The cutting force variation curves of the soil cutter under different rake angles and soil cohesion are obtained.
(iii) The performance test of the model 3PF-240 is carried out. The results show that the simulation analysis results are basically consistent with the test results. The validity of the simulation model is validated, and the suggestion of changing rake cutters for different soil environments is put forward to improve the adaptability of the operation.

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