Matching of Cutting and Feeding Speed for Reaping *Arundo donax* L. Based on ANSYS/LS－DYNA*

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Abstract

The crops with thick-tall stem are difficult to be harvested by machine due to hardness and stiffness of the stem. In the present study, a dynamic simulation model of *Arundo donax* L. penetration was established by finite element numerical simulation technology, of which based on a general rotary-chain cutter for thick-tall stem. The results showed that the optimized matching parameters of cutting process for cutting and feeding speed were 2.80 m/s and 1.00 m/s, respectively. The optimal correction factor of cutting process for *Arundo donax* L. was 1.22. The study provided a methodological basis for the analysis of cutting process for thick-tall stems.

Key words　*Arundo donax* L., ANSYS/LS－DYNA, High-speed photography, Cutting process, Thick-tall stem crop

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Introduction

For thick-tall stem crops, it is very hard to cut by manual or machine due to hardness and stiffness and the specific biological characteristics. It is the greatest obstacle for the large-scale cultivation of these crops. The existing researches mainly focused on harvester for corn and sugar cane, and those researches have achieved good results in this field[1~4]. But few study was focus on other thick-tall stem crops, like giant reed (*Arundo donax* L.), which is the good raw material of papermaking.

Aiming on the harvest issue of *Arundo donax* L., a general rotary-chain cutter was developed[5]. The initial field test demonstrated that this cutter was able to apply in a harvest machine of *Arundo donax* L., but further research of its structures and parameters was necessary for optimizing the efficiency of harvest[6]. Especially for the matching of cutting speed of the cutter and the feeding speed of the machine, it was one of the key factors affecting energy consumption, cutting quality and efficiency of the harvester. But the actual situation and working condition of the cutter and cutting process was complex, and was difficult in analyzing. In the present study, numerical simulation and high-speed photography will be used to explore the matching of cutting and the feeding speed.

1　Finite Element Model of Cutting Process

The researches on some physical and mechanical parameters of the bottom stem of *Arundo donax* L. in harvest period have been carried out previously[7]. It indicated that *Arundo donax* L. might be approximated as transversely anisotropic material, and had complex structure as a biological material, but the characters like viscoelastic and anisotropy had not been well reflected[8]. In order to comply with the regulation of the software ANSYS/LS－DYNA, making reference to relevant literature of agricultural materials[9], the mechanical properties of wood[10] and bamboo[11~12], the *Arundo donax* L. material was simplified as motivated plastic materials, which material parameters were input as: elastic modulus 0.8 GPa, Poisson's ratio 0.34, density 0.55×10^{-3} g/mm^3, yield strength 0.01 GPa and shear modulus 0.32 GPa. According to statistic result of the growth of *Arundo donax* L. in the field, the geometric parameters were defined, including 24 mm as external diameter D, 17 mm as the internal diameter d, 2.5 mm as thickness of node s, and 300 mm as length of single-section with

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both side nodes. In addition, the enhancing phenomenon of node fibroblast was neglected.

The serrated prototype was the blade of the cutter, which is of double-metal composite[13], material parameters being approximated as steel, and simplified as linear elastic material in numerical simulation model with 21.0 GPa as elastic modulus, 0.284 as Poisson's ratio and 7.5 g/mm^3 as density [14], while the geometric parameters were input, including 50 mm as saw width b, 3.5 mm as tooth depth h, 8 mm as distance between teeth t, 33° as front cutting angle α, 47° as tooth vertex angle β, and 10° as back cutting angle γ [13].

The cutting model of *Arundo donax* L. (Fig. 1) was established by using solid164 element, defining the contact as CONTACT_ERODING_SURFACE_TO_SURFACE between blade and *Arundo donax* L., where blade was contact component and *Arundo donax* L. was target component. The part near the contact region was meshed by improved grid density in order to enhance the solution accuracy without more increase of computation quantity. Both sides of *Arundo donax* L. were imposed constraints.

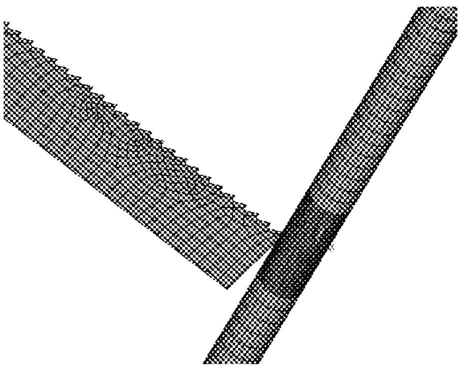

Fig. 1 Finite element model of *Arundo donax* L.

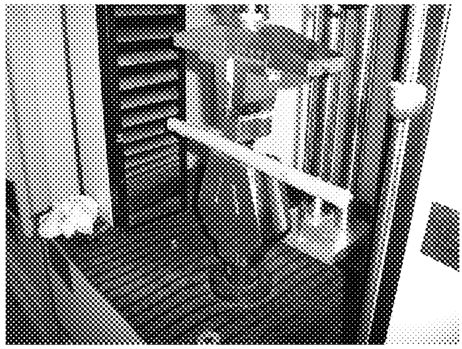

Fig. 2 Load − displacement test of *Arundo donax* L. penetration

2 Verification Experiment

2.1 Loading and Displacement Experiment

The RGT computer − servo material testing system (Shenzhen Rreger Instrument Co., Ltd., Guangdong) was used in the test, of which the type was RGT − 10, the specification was 10 kN, the precision of rank was ±0.5%. As the experiment system shown in Fig. 2, the blade was fixed by fixture, *Arundo donax* L. sample could be vertically cut with various velocities. This experiment system offered the load − displacement result of destroy test as curve which was utilized to confirm the numerical simulation model.

2.2 Cutting Process Experiment

The experiment system was consisted of two subsystems: the test-bed based on the general rotary-chain cutter and a high speed video subsystem. The self-designed test-bed was shown in Fig. 3. The high speed video subsystem included a Mikrotro's speed camera MC1311, a Nikko's lens ZOOM − Nikkor and an image capture board INSPECTA − 5 Frame Grabber which was installed in the high-powered computer. This system was used to analyze the cutting process with the images of the ultra-short process of the blade cutting down *Arundo donax* L. at various cutting condition.

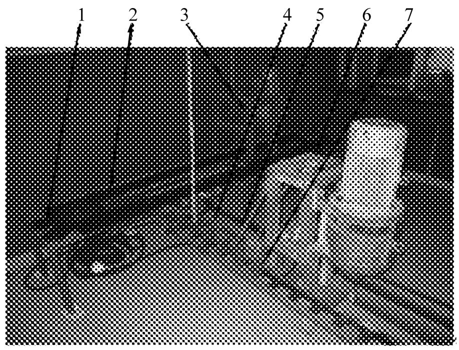

Fig. 3 Test rig of cutting process

1. Cutter platform 2. Cutter 3. Cutting power 4. Feeding platform 5. Feeding chain 6. Feeding power 7. Fixture of *Arundo donax* L.

3 Results and Discussion

3.1 Numerical Simulation Analysis

The load − displacement curves (the cutting speed $v_x = 3.00$ mm/s, the feeding speed $v_y = 0$ mm/s) were shown in Fig. 4. The thick curve was came from the disposal of numerical simulation by software namely LSPREPOSTD, while the thin curves were came from loading and displacement experiments. The figure indicated that the curves of numerical simulation and real test were consistent, and both maximal loadings of damage were nearly 450 N. Comparing the damage of *Arundo donax* L. in numerical simulation and the damage of *Arundo donax* L. in real test (Fig. 5), it could be concluded that the damages were similar. Both of the load − displacement curves and breach situation were confirmed the validity and feasibility of the numerical simulation model.

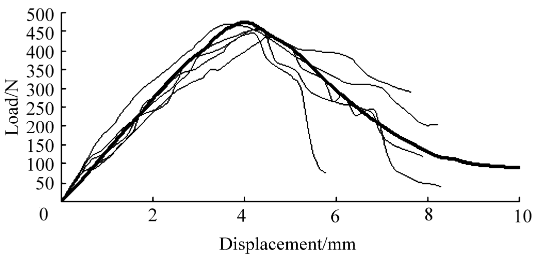

Fig. 4 Load - displacement curves with saw speed of 3.00 mm/s

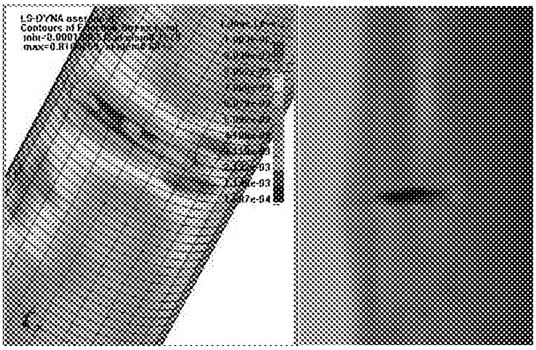

Fig. 5 *Arundo donax* L. breach situation with saw speed of 3.00 mm/s

3.2 Optimal Cutting and Feeding Speed

Based on the high video image analysis under various speed, the cutting process observing experiment revealed that a big value of feeding speed would make it impossible for cutter to cut down *Arundo donax* L., in detail, the cutting could not be achieved if the feeding speed v_y exceeded 1.38 m/s while whatever the cutting speed v_x was. Several images captured at 2 000 frame per second by the high-speed video subsystem were showed Fig. 6. Fig. 6a presented the cutting situation when $v_x = 3.50$ m/s and $v_y = 1.50$ m/s. The stems were torn apart by the cutter. The stem was torn apart by the cutter. Fig. 6b illustrated how the cutter pushed over the stems entirely when $v_x = 3.50$ m/s and $v_y = 2.00$ m/s. On the other hand, a small value of feeding speed would cause the cutter working of low efficiency. Considering both the harvester and working condition, the feeding speed v_y was set at 1.00 m/s.

It was known that when the blade moved a tooth depth along feeding way and it also moved two teeth spaces along the cutting way, each track of blade movement was neither superposition nor gap in perfect surrounding. The matching between cutting and feeding speed would be optimal. In this paper, λ was defined to describe the ratio of cutting and feeding speed matching as

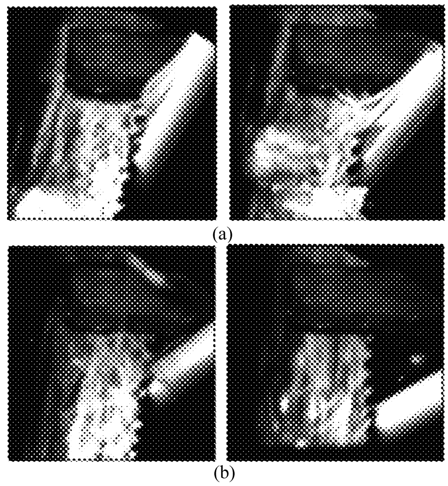

Fig. 6 Image of cutting process of *Arundo donax* L. captured by high-speed video capture

(a) $v_x = 3.50$ m/s and $v_y = 1.50$ m/s

(b) $v_x = 3.50$ m/s and $v_y = 2.00$ m/s

$$\lambda = \frac{v_x}{v_y} = \frac{t}{h}$$

Tests revealed that when the speed of cutting and feeding was defined according to the perfect ratio λ, *Arundo donax* L. could not be cut down in proper condition, while theory analyses demonstrated that the value of the perfect ratio should be insufficiency without considering *Arundo donax* L. stem rebounding and contacting with the gingiva during cutting process. In order to settle this problem, the concept of correction factor about the matching speed of cutting and feeding was presented as μ, which value should be changed along with the species of thick-tall stem crop. The optimal matching ratio was defined as

$$\lambda_A = \mu \frac{v_x}{v_y} = \mu_A \frac{t}{h}$$

where, μ_A—the correction factor about *Arundo donax* L.

λ_A—the ratio of optimal matching

Numerical simulation results with various v_x under the same feeding speed ($v_y = 1.00$ m/s) indicated that if $\mu_A < 1.20$ m/s, namely $v_x < 2.74$ m/s, *Arundo donax* L. could not be cut down. As Fig. 7 showed, when $v_x = 2.70$ m/s, $v_y = 1.00$ m/s, *Arundo donax* L. had distortion without damage, and the numerical solution alarmed. Fig. 8 showed cutting status of successful solution when $v_x = 3.80$ m/s, $v_y = 1.00$ m/s, of which *Arundo donax* L. was cut off by blade.

Tab. 1 showed the maximal power and the average energy of single *Arundo donax* L. being cut down by blade under various cutting velocities. It showed that single *Arundo donax* L. cutting energy consumption would increase along cutting speed increase.

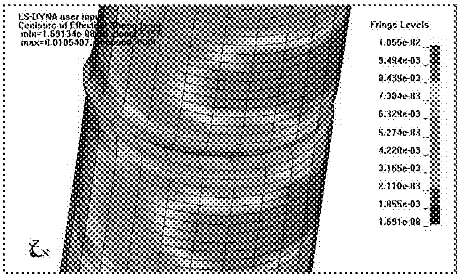

Fig. 7　*Arundo donax* L. breach situation with sawing speed at 2.70 m/s

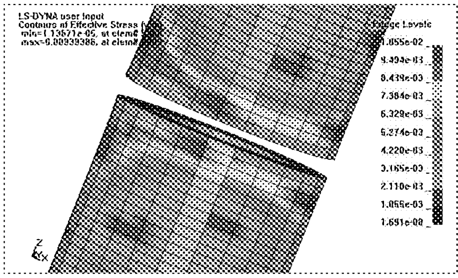

Fig. 8　*Arundo donax* L. breach situation with saw speed at 3.00 m/s

Considering the vibration of the actual work and other practical condition, when the feeding speed of was 1.00 m/s, the optimal cutting speed was 2.80 m/s, and the correction factor of matching ratio was 1.22.

Tab. 1　Sawing performance parameters

Parameters	v_x/m·s^{-1}						
	2.80	3.00	3.20	3.40	3.60	3.80	4.00
Max power/W	1 436.7	1 298.1	1 956.4	2 335.1	2 179.2	1 719.5	2 514.1
Average energy/J	18.4	22.6	35.2	29.0	40.0	33.2	47.1

4　Conclusions

(1) The numerical simulation model of the cutting process was established based on ANSYS/LS－DYNA and was confirmed through comparing the load－displacement curves and damage status of numerical simulation and experimentation.

(2) The cutting process experiment indicated that the cutting should not be achieved if v_y > 1.38 m/s while whatever v_x was, the optimal feeding speed was 1.00 m/s.

(3) The concept of correction factor of the rate of cutting and feeding speed was presented; the numerical simulation indicated that the value must be more than 1.20 m/s when the general rotary-chain cutter being used to reap *Arundo donax* L.

(4) The energy consumptionfor cutting single *Arundo donax* L. was increased along with the cutting speed increase. The optimal matching parameters of cutting process for cutting and feeding speed were 2.80 m/s and 1.00 m/s, respectively. And the optimal correction factor of cutting process for *Arundo donax* L. was 1.22.

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基于ANSYS/LS－DYNA的芦竹切割-进给速度匹配研究

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【摘要】 高粗茎秆作物因茎秆硬度和刚度大，机械化收割难度大。以芦竹为对象，以高粗茎秆作物通用型回转链式切割器为基础，应用ANSYS/LS－DYNA建立了锯片-芦竹切割破坏动态模拟有限元模型，动态模拟了芦竹切割破坏过程，试验验证了获取锯齿切割破坏芦竹过程的载荷-位移历程曲线的可行性及芦竹破坏的模拟计算模型的有效性。提出了回转链式切割器切割-进给速度匹配修正系数概念，确定了切割芦竹时进给速度和切割速度分别取1.00 m/s和2.80 m/s为最佳速度匹配，其切割器工作速度匹配修正系数为1.22。研究结果为芦竹收割机的传统系统参数优化设计提供了理论依据。

关键词：芦竹 ANSYS/LS－DYNA 切割过程 高粗茎秆

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