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Flexible Plate Teeth Type Sugarcane Leaf-Stripping Device

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Abstract

In sugarcane combine harvesting, not hulling rate and damage rate of sugarcane in the process of leaf stripping are rather high. Thus, multiple flexible leaf stripping system was proposed. Making using of general multiple flexible leaves stripping to sugarcane, leaf-stripping device with flexible plate teeth was developed. On the basis of the four-factor second order rotation combination experiment, a neural network prediction model between working performance influence factor and index was established. And according to using BP neural network and Genetic Algorithm, the facility parameter optimization was performed. The best parameter combination for the facility was the rotational speed of inlet roller 623.2r/min, the rotational speed of first order leaf-stripping roller 951.6r/min, the rotational speed of second order leaf stripping roller 1129.4r/min, the rotational speed of deliver roller 846.7r/min. The results show that a new approach for performance prediction model building and parameter optimization of sugarcane leaf-stripping device with flexible plate teeth, combining BP neural network with Genetic Algorithm is reliable, accurate and feasible.

Keywords*: Sugarcane， Leaf-stripping device, Flexible plate teeth, BP neural network, parameter optimization*

1. Introduction

Leaf-stripping is an important link in process of sugarcane harvest, and the performance of leaf-stripping device of sugarcane harvester directly affects the final quality of pressing sugarcanes[1]. So far, a lot of theoretical and testing researches for mode and mechanism of leaf-stripping, performance and material of cleaning elements *etc*. had been done by domestic and foreign experts[2-14].

There are three kinds of leaf-stripping device used in existing sugarcane harvesters, which contains rubber-finger-drum style, steel-wire-drum style, and airstream style[2]. Moreover, these modes remove leaves from sugarcane stalk respectively by blow force of rubber fingers and friction force between rubber fingers and the stalk among them, friction force between steel wires and sugarcane leaves, and airflow action of high speed and high pressure. It is reported that there were still some problems in those leaf-stripping devices, such as easily damaged of stalks, short life of cleaning elements or high not hulling rate[2-6]. Therefore, this study designed a sugarcane leaf-stripping device with flexible plate teeth, meanwhile built the performance prediction model of this device, and then performed the parameter optimization of it.

2. Structure and Working Principle

2.1. Structure of Leaf-Stripping Device

The leaf-stripping device with flexible plate teeth mainly composed by frame, cleaning

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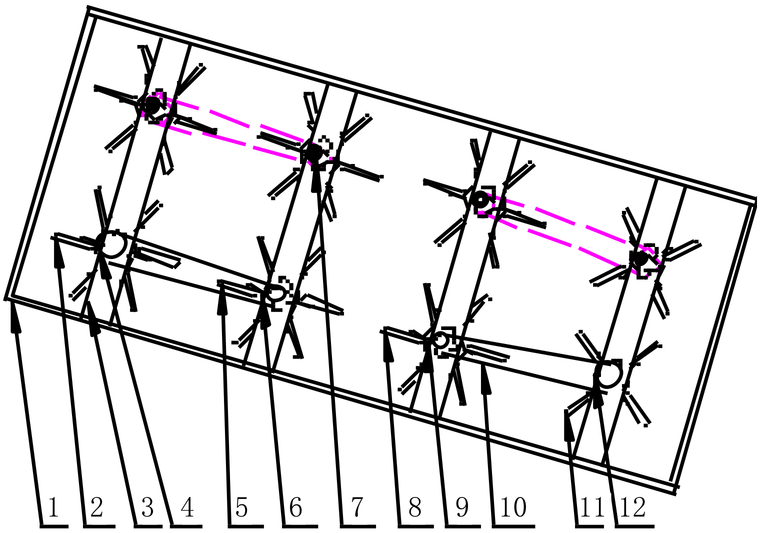
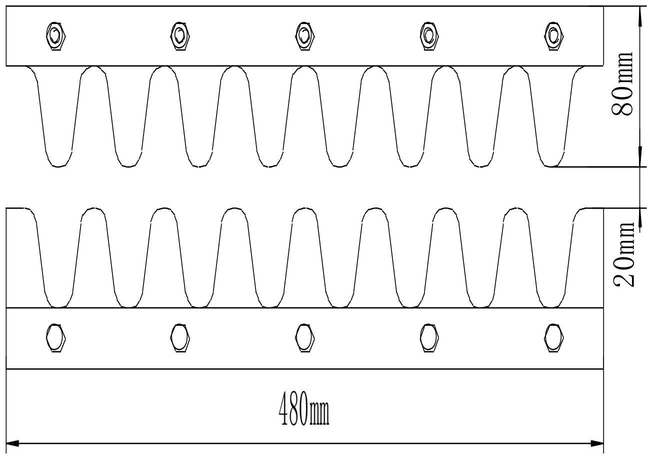
elements, four pairs of drums with adjustable gap, as shown in Figure 1. In order to ensure matching ability between this device and sugarcane harvester, meanwhile uniformly forced in leaf-stripping process and little injury of the stalk, the leaf-stripping drums were symmetrically distributed upper and lower (drums with cleaning elements were called leaf-stripping rollers while with the same direction and equal rotational speed). Moreover, the main parameters of this device were determined such as inlet roller diameter of 260mm, other rollers diameter of 270mm, transverse space between the adjacent two groups of leaf-stripping roller of 500mm, and angle between the device axis and ground of 16°. In addition, the cleaning elements with flexible plate teeth were shown in Figure 2, and the material of them was wear resistant rubber. Furthermore, four and six pieces of cleaning elements were respectively uniformly distributed in inlet roller and other rollers.



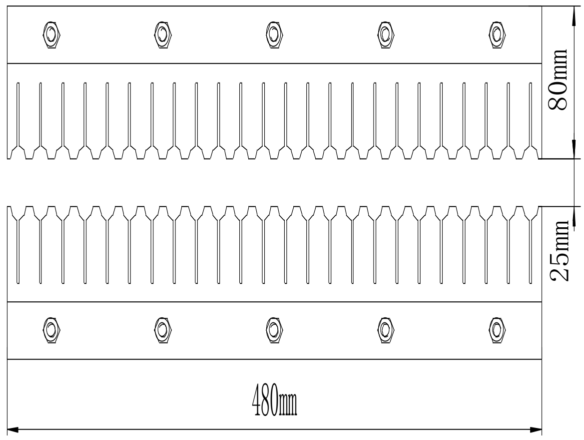
1,3. Frame 2,5,8. Cleaning element Ⅰ 4. Deliver roller 6. Second order leaf- stripping roller 7. Bearing chock 9. First order leaf-stripping roller 10. Transmission chain 11. Cleaning element Ⅱ 12. Inlet roller

Figure 1. Test Device of Sugarcane Leaf-Stripping with Flexible Plate Teeth

In Figure 2, cleaning element of No. 1 was used in inlet roller; the average diameter of sugarcanes was 28±4mm by test measurement. In order to grasp and feed the sugarcanes favorably, the minimum leaf-stripping clearance of inlet roller was taken as 20mm. Further, a flexible arc teeth design was adopted for cleaning element of No. Ⅰ. Cleaning element of No. Ⅱ was used in other rollers, and a flexibly rectangular plate teeth design was adopted for it. So this design is more active for attack and friction effect of sugarcanes. Meanwhile, for reducing the injury of sugarcane stalks, the leaf-stripping clearance of other rollers was taken as 25mm.



(a) Cleaning element Ⅰ



(b) Cleaning element Ⅱ

Figure 2. Cleaning Elements

2.2. Working Principle

In working process, with leaf-stripping rollers rotating, the cleaning elements made uniform circular motion with different speeds. When the root of sugarcane was touched with cleaning elements of inlet roller, it was immediately hit and extruded into the device. Furthermore, upper and lower cleaning elements made intimate contact of leaves and stalks then producing a certain pressure. So, the sugarcanes were successfully fed. Subsequently, the sugarcanes continued by crossing first order leaf-stripping roller, second order leaf-stripping roller and deliver roller, meanwhile repetitive hit, extrusion and friction of leaves and stalks were realized. Then the stalks and loose leaves were thrown out from the device, and separated by their self-weight.

3. Establishment of Performance Prediction Model of the Device

The main performance influence factors of leaf-stripping device with flexible plate teeth were determined: the rotational speed of inlet roller x1, the rotational speed of first order leaf-stripping roller x2, the rotational speed of second order leaf-stripping roller x3, the rotational speed of deliver roller x4. The test indexes were not hulling rate y1 and damage rate of sugarcanes y2 which were taken by sugar manufactured enterprises to measure the quality of pressing sugarcanes. In addition, the training data of BP network was constructed by using four-factor second order rotation combination experiment.

The test material was natural maturity sugarcanes Tai Tang 22 in the same year. The average height was 2000±18mm, the average diameter was 28±4mm, the moisture content of sugarcane leaves was 23%, and the leaf stem ratio was 7.2%. The sugarcanes feeding were used by the belt device for simulating the sugarcane harvester working, and the feed rate was 2.8kg/s. The test times were 31, then after every time the quality of loose leaves, residual leaves, injured stalks, and total stalks were respectively weighed. Furthermore, the test index value was obtained. So, factors and levels of the experiment was illustrated in Table 1, meanwhile the test scheme and prediction results as shown in Table 2.

Table 1. Factors and Levels of Experiment

Level code	x_1/r/min	x_2/r/min	x_3/r/min	x_4/r/min
Upper asterisk arm (+2)	900	1000	1150	1150
Upper level (+1)	812.5	912.5	1062.5	1037.5
Zero level (0)	725	825	975	925
Lower level (-1)	637.5	737.5	887.5	812.5
Lower asterisk arm (-2)	550	650	800	700
Constant intervals Δj	87.5	87.5	87.5	112.5

3.1. Implementation of BP Network Prediction Model

The test conditions and results were taken as input-output pattern pairs of BP network, after normalization processing of input vector, the final structure parameters of BP network were confirmed by contrastive experiments: the unit number of input layer, single hidden layer and output layer respectively was 4, 6, and 2. Further, the structure of BP network prediction model for this study was shown in Figure 3. Then, we selected the learning coefficient of 0.05, the momentum coefficient of 0.8, and the global error of 0.00004, through the iteration of 20 times, the error function tended to be stable, as shown in Figure 4. The final learning outcome was illustrated in Table 2, which No.11, 13, 15 were the output of prediction test sample.

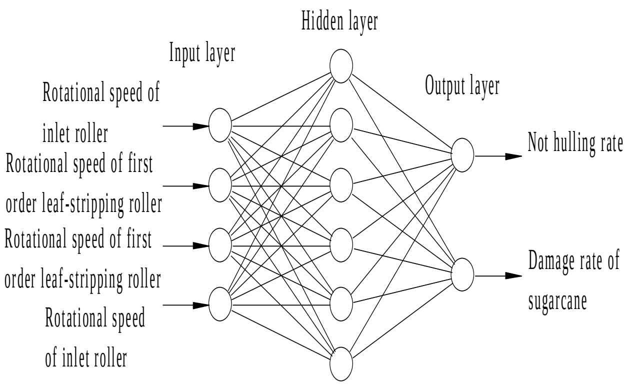


Figure 3. The Prediction Model of Leaf-Stripping Device

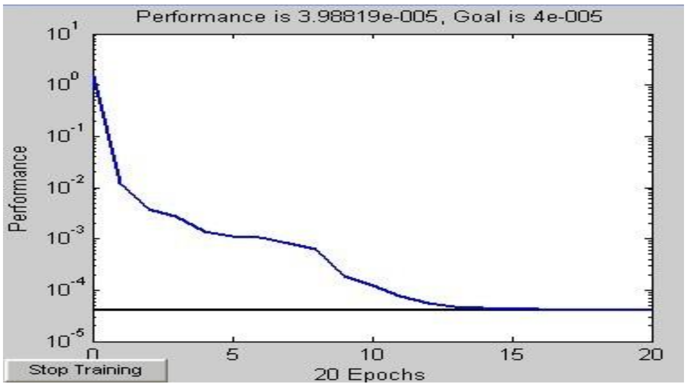


Figure 4. BP Neural Network Training Error

3.2. Analysis of Prediction Results

After the network training was finished, through using the sim function, the test data of prediction test sample No.11, 13, 15 which randomly selected were inputted into it for simulation test. The relative error between prediction results and measured values of not hulling rate and stalks damage rate was illustrated in Table 3.

Table 2. Four-Factor Second Order Rotation Combination Experiment and Results

Test number	Experiment factors				Measured values		Values based on BP network	
	x	x	x	x	y_1	y_2	y_1	y_2
1	1	1	1	1	0.407	0.012	0.404	0.0127
2	1	1	1	-	0.364	0	0.3642	0.0025
3	1	1	-	1	0.397	0.055	0.3982	0.0544
4	1	1	-	-	0.387	0.042	0.3832	0.0415
5	1	-	1	1	0.374	0	0.3697	0.0021
6	1	-	1	-	0.386	0.051	0.3812	0.0504
7	1	-	-	1	0.378	0.061	0.3761	0.0612
8	1	-	-	-	0.343	0	0.3399	0.0009
9	-	1	1	1	0.334	0	0.3352	0.0002
10	-	1	1	-	0.329	0.055	0.3285	0.0555
11	-	1	-	1	0.359	0.018	0.3595	0.018
12	-	1	-	-	0.353	0.069	0.3528	0.0688
13	-	-	1	1	0.369	0	0.3665	0.0001
14	-	-	1	-	0.363	0.059	0.3659	0.06
15	-	-	-	1	0.383	0	0.3786	0.0012
16	-	-	-	-	0.361	0.025	0.3615	0.0263
17	-	0	0	0	0.341	0.055	0.3315	0.0414
18	2	0	0	0	0.338	0.033	0.3456	0.0644
19	0	-	0	0	0.350	0	0.3595	0.0005
20	0	2	0	0	0.413	0	0.4126	0.0009
21	0	0	-	0	0.324	0.030	0.3236	0.029
22	0	0	2	0	0.326	0	0.3305	0.0012
23	0	0	0	-	0.337	0.028	0.3368	0.029
24	0	0	0	2	0.353	0.032	0.3609	0.0345

25	0	0	0	0	0.335	0	0.3387	0.02
26	0	0	0	0	0.348	0.038	0.3387	0.02
27	0	0	0	0	0.346	0.02	0.3387	0.02
28	0	0	0	0	0.335	0.016	0.3387	0.02
29	0	0	0	0	0.329	0	0.3387	0.02
30	0	0	0	0	0.331	0.046	0.3387	0.02
31	0	0	0	0	0.342	0.019	0.3387	0.02

Table 3. Error of Prediction Results of BP Neural Network Model

Test number of forecast sample	Based on BP network	
	Relative error of not hulling rate/%	Relative error of damage rate of sugarcane/%
11	0.14	0
13	0.68	0.01
15	1.15	0.12

Data in Table 3 shows that the prediction error of BP network prediction model was less. Therefore, the performance prediction model of leaf-stripping device with flexible plate teeth was effective.

4. Parameter Optimization Analysis

4.1. Parameter Optimization for Prediction Model Based on Genetic Algorithm

The simulation results of BP network model namely sim(net, y) were taken as fitness function, because of the output $y = \begin{Bmatrix} y_1 \\ y_2 \end{Bmatrix}$ of two-dimensional, the corresponding dimension was used as each sub-objective function. Let initial population size be 200, namely each sub-population size was 100; employed the binary system coding; set the selected function of random ergodic sampling (sus); the crossover operator was alone point crossing (xovsp) and its probability was 0.8; the mutation operator was discrete mutation (mut) and its probability was 0.005; the iterative number was 50, and the searching range of variables was the range which after normalization processing of input parameters from test sample.

Finally, through using the genetic algorithm toolbox which developed by Sheffield University based on MATLAB[15], the programming operational was carried out. When the iteration closed to 50th generation, each sub-goal value tended to be stable.

The output results of parameters optimization were as following: not hulling rate of sugarcanes y1=29.45%, and damage rate of sugarcane stalks y2=1.52%; the corresponding parameters after inverse normalizing were that the rotational speed of inlet roller 632.2r/min, the rotational speed of first order leaf-stripping roller 951.6r/min, the rotational speed of second order leaf stripping roller 1129.4r/min, the rotational speed of deliver roller 846.7r/min.

4.2. Verification Analysis of Optimization Results

In order to prove the reliability of the optimization results, we completed the verifying test by using the same batch of sugarcanes. The sugarcanes after test were shown in Figure 5.

Figure 5. The Sugarcanes after Test

The results of verifying test were illustrated in Table 4.

Table 4. Experimental Scheme and Results for Prediction Verification

Test number	Test scheme				Results	
	x_1 /r/min	x_2 /r/min	x_3 /r/min	x_4 /r/min	y_1/%	y_2/%
Optimal values	623.2	951.6	1129.4	846.7	29.45	1.52
Verification 1	623	950	1127	845	30.13	1.45
Verification 2	621	952	1130	844	29.56	1.62
Verification 3	625	952.5	1128	847.5	28.89	1.50

It was shown that the predictive values were quite closed to test results, so this performance prediction and optimization model established by BP network combined with Genetic Algorithm was reliable and practical.

5. Conclusions

A sugarcane leaf-stripping device with flexible plate teeth was designed, which principal working parts were four pairs of rollers with adjustable gap, as well as cleaning elements with flexible plate teeth.

The BP network prediction model for forecasting the performance of this device was established; meanwhile the performance prediction results for this device were accurate and credible.

The optimum parameter combination of this device was that: the rotational speed of inlet roller was 632.2r/min, the rotational speed of first order leaf-stripping roller was 951.6r/min, the rotational speed of second order leaf stripping roller was 1129.4r/min, and the rotational speed of deliver roller was 846.7r/min. Under this parameter combination, through test verifying, the average not hulling rate was 29.5%, and the average damage rate of sugarcane was 1.52%.

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