Small Sugarcane Harvester Conveying Failure Analysis

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Abstract—The small sugarcane harvester is the main model that it is fitted for hilly areas, but it is vulnerable to conveying failure. To breakthrough the limitation of individual harvester`s structural improvement traditionally, Traditionally structural improvement to the individual harvester is not generally effective to solve it. This paper finds that the relationship between the randomness of the sugarcane growth and the harvester conveying capabilities should be taken into consideration so as to avoid the conveying failure risk of sugarcanes stacking up. Queuing theory is introduced to establish the mathematical model of cane feeding to and conveying through the harvester and the analysis shows that the higher the speed of sugarcane conveying the less possibility there is congestion. Using virtual simulation technology, this paper simulates the process of canes flow feeding into the harvester based on FLEXSIM and finds that increasing conveying speed from 0.8 m/s to 1.6 m/s would lead to the possibility of congestion being reduced from 20.3%to 6.28%.This paper proposes a way to increase the conveying speed of the harvester by minor retrofit without increasing the driving power. Field experiment shows that the congestion rate is getting lower as the conveying speed increases and it is better to keep the conveying speed at least higher than 1.1m/s. Therefore, improving the conveying speed provides a new idea to reduce conveying congestion for the small scale sugarcane harvester.

Keywords—small sugarcane harvester; conveying failure; queuing theory; virtual simulation

I. INTRODUCTION

Production mechanization is taken as the key to the sugar industry development in China and become more and more important as the lack of labor and cost increases [1]. As most sugar canes are planted on hilly areas, for quite a long time the small style sugarcane harvester has been the main stream [2]. However, its sugar cane conveying channel width is relatively narrow as only 0.3m, congestion is often encountered, especially for large, lodged and tangled canes.

Generally speaking, the reasons are mainly laid on two aspects. On the one hand, it is due to the agronomic factors, on the other hand, it is for the incompetence of harvester conveying capability. As the agronomic factors is difficult to control for harvester researcher, improving harvester conveying capacity is attached most importance.

Due to the limitation of compaction of the harvester, increasing conveying force is the most direct method, such as increased engine power. However, it simultaneously brings damage to the sugarcane stalk and more extraneous matter [3][4]. Reducing resistance by improving harvester structure is another way, especially in the bottleneck location. Otten [5] designed a tangled sugarcanes separating device and auxiliary rollers to limit canes transport direction to reduce the congestion. Li lixin [6] designed an anti-overlapping device for the small style sugarcane harvester using screw drive to prompt sugarcane evenly distributed in the conveying channel. McCarthy [7] researched on using mechanical and electrical technology, such as chemical sensors to automatically control cutting sugarcane tops, thereby effectively reducing sugarcane tops plugging in conveying channel. Gupta [8] studied the relationship between the conveying congestion and the kinematic parameters of the single disc rotating cutter. Norris. and Davis [9] adjusted the spiral angle and the diameter of the spiral roller, optimized the working angle of the knockdown and finned roller and added two disc cutters so as to reduce conveying congestion right at the entrance of the feeding channel. Norris and Davis also verified by the field trials the effect of changing the double helix spirals to single ones, installing more forward the cutting system, lowering the conveying channel uplift angle. Mo Zhaofu, Ou Yinggang [10] designed auxiliary feeding rollers, with adjusting springs which could enrich the adaptability to sugar cane diameter alternativeness. As to the research technology, virtual prototype technology is mainly applied. Davis, R.J. and Schembri, M.G. [11] used finite-element modeling to simulate the flow of cane through the harvester with alternative component positions. Pu Minghui [12] by using dynamic simulation software ADAMS, designed a kind of feeding finned roller to enhance the harvester feeding ability. Li wan [13] later redesigned a new feeding system and verified its effect by virtual experiment on dynamic simulation models. Some researchers even studied the whole conveying system of the harvester and analyzed each sector conveying capability one by one using virtual prototype technology.

These researches are beneficial to find out some measures to reduce congestion of some models of the harvester. Nevertheless, as there are so many types of harvester, these measures may not be effective to all sugarcane harvesters. Mathematic model of the conveying process of the sugarcanes in the harvester is necessary to be built to analyze the mechanism of conveying congestion.

To begin with, the analysis of the relationship between sugarcanes and the harvester may reveal the key factors of the conveying congestion: sugarcanes, growth distribution, height, diameter are random, which in their turns would lead to the random change of the feeding amounts and processing time to the harvester. Uneven sugarcane feeding flow would then appear. As the harvester feeding capability is fixed while feeding flow amount changes randomly, it is hard to make a real-time match for them. Therefore, sugarcanes would often stack up in the bottleneck position of the conveying channel, resistance exaggerating several times or dozen times. That is where the peak of the resistance shows. So it is crucial to control conveying congestion by avoiding sugarcanes stacking up when feeding .For this, the first step is to make a survey of the sugarcane growth.

II. SUGARCANE GROWTH RANDOMNESS SURVEY

According to the research survey that our team made, the sugarcane density distribution is belonged to Poisson Distribution. Measuring 119 times of the sugarcane distribution density in fields randomly selected. There are 984 sugar canes in 119 m length of planting row, so the average canes density is 8.27 canes / m. Hypothesis testing showed that it belongs to the Poisson distribution. Similarly, the sugarcane height distribution belongs to Normal Distribution by hypothesis testing. Results are shown in figure 2. The average cane height is 2.326 m and the Variance is 3.380 m. Results are shown in Figure I.
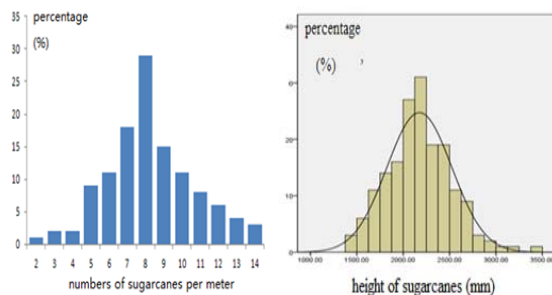

FIGURE I. DENSITY OF SUGARCANE DISTRIBUTION FREQUENCY AND SUGARCANE HEIGHT FREQUENCY

III. Mathematic Model of Sugar Cane Feeding and Conveying in Harvest

In order to make the research results more generally fitted for most sugar cane harvester, a kinematics model of the process of sugarcane feeding and conveying in harvester is necessary to build up. Motion of a single sugar cane is not difficult to analyze in regular mathematics model, but as to the random flow of sugar cane it is a challenge. So the queuing theory is introduced. Queuing theory has been widely used in modern industry, transportation, and telecommunications, but it is seldom used in agriculture, especially in the analysis of the sugarcane harvest [14] [15].

Taking sugarcane flow as the serving object, the feeding channel accommodation capability converted in the numbers of service stations, the service rule as first come first service, conveying time is subjected to the distribution of the sugarcane

height as Normal Distribution, and sugarcane flow arriving time is subjected to the sugarcane density distribution as Normal Distribution. So this condition conforms with the queuing system M/G/K model. Then:

Retention time for each sugar cane to feed in harvester:

$$W_q = \left[\frac{D[S] + (E[S])^2}{2E[S][K - \lambda E[S]]} \right] \left[1 + \sum_{i=1}^{k-1} \frac{(k-1)![k - \lambda E[S]]}{i![\lambda E[S]]^{K-i}} \right]^{-1} \quad (1)$$

Total processing time for each sugar cane to convey through the harvester is

$$W = E[S] + W_q \quad (2)$$

Numbers of detained sugar canes:

$$L_q = \frac{\lambda d[S] + (\lambda[S])^2}{2E[S][K - \lambda E[S]]} + \left[1 + \sum_{i=0}^{K-1} \frac{(K-1)![K - \lambda E[S]]}{i![\lambda E[S]]^{K-i}} \right]^{-1} \quad (3)$$

here: *l* - sugar cane feeding frequency, is equal to the sugar cane planting density multiply harvester walking speed;

K–numbers of canes that conveying channel can accommodate in max;

E[S]-average time needed for one cane conveying through the harvester;

D[S]-variance time for one cane conveying through the harvester;

According to (3), the more the forward speed of the harvester and the amount of simultaneous feeding canes, the more the numbers of stacking up sugar canes and the more possibility of congestion happens. The following Table I shows the small sugarcane harvester forward speed increased from 0.18 m/s to 0.55 m/s and sugar cane feeding frequency increased from 1 to 3 per second, the possibility of congestion increases from 2.11% to 17.56%.

TABLE I. CONGESTION RATE (%) AND RETENTION TIME WITH VARIOUS FORWARD SPEED AND FEEDING FREQUENCY.

Forward Speed(m/s)	Feeding frquency(/scond)	Retention time(S)	Congestion rate (%)
0.18	1.0	0.215	2.11%
0.27	1.5	0.271	3.91%
0.36	2.0	0.365	6.81%
0.45	2.5	0.560	12.29%
0.55	3.0	0.711	17.56%

Moreover, according to (3), the key to eliminate the stacking up canes is to increase harvester conveying speed. The higher the sugarcane is, the faster the conveying speed needs to be. The virtual logistics simulation experiment following shows the specific impact of conveying speed to congestion.

IV. Logistics Simulation Experiment

Logistics simulation models of canes conveying through the harvester are built in FLEXSIM software to compare the congestion rate in various conveying speeds. As the conveying speed is not a direct input parameter in FLEXSIM, it needs to be converted. When the conveying speed is 0.8 m/s 1.2m/s and 1.6m/s, the average processing time varied as 2.91 s, 1.94 feeding time interval for each sugar cane is set as 0.33 seconds, the conveying channel width as capable to accommodate 10 to 15 canes in max, and the total simulation time is 60000 seconds. The process under these three conditions is simulated respectively. With the statistical confidence interval of 95%, the results of coveying speed varied from 0.8m/s to 1.6m/s with channel accomdation width 10 canes are shown as following Figure II and the other simulation results while channel accomdation width varied from 10 canes to 15 are shown in Table II ~ Table III.
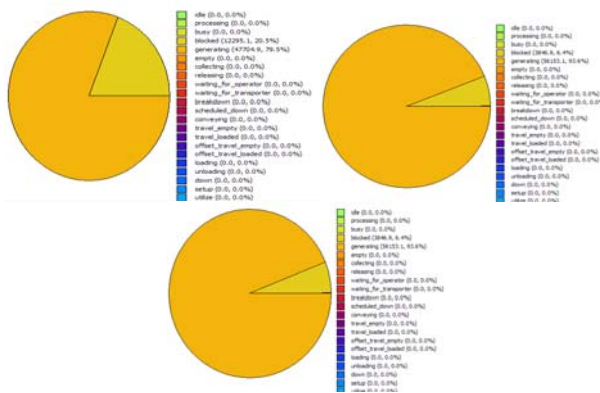

FIGURE II. CONGESTION RATE WHEN CONVEYING SPEED IS 0.8M/S,1.2.M/S,1.6M/S

TABLE II. CONGESTION RATE (%) WITH VARIOUS CONVEYING SPEED IN WIDTH OF CHANNEL 10 CANES

	Conveying speed(m/s)		
	0.8	*1.2*	*1.6*
Congestion rate	20.30	10.10	6.28

TABLE III. CONGESTION RATE (%) WITH VARIOUS WIDTH OF CHANNEL IN CONVEYING SPEED 1.6M/S

	Width of channel (amounts of sugarcane)					
	10	*11*	*12*	*13*	*14*	*15*
Congest ion rate	6 .28	4 .64	3 .44	2 .56	1 .92	1 .42

From the Figure II to IV and Table II ~Table III, it can be seen that when the conveying speed varied from 0.8 m/s to 1.6 m/s with channel accommodation width 10 canes, the congestion rate is reduced from 20.3% to 6.28%. Moreover, when keeping conveying speed at 1.6 m/s, channel accommodation width varied from 10 canes to 15 canes, the congestion rate is even reduced from 6.28% to 1.42%.

That is to say, improving the conveying speed and enlarging the channel accommodation width could significantly reduce the congestion rate. As conveying channel width is constrained to the small size of the harvester, improving the conveying speed would be the main method to reduce the congestion rate.

V. Measures to Improve the Conveying Speed without Increasing the Driving Power

The simplest and effective way to improve the conveying speed without increasing the driving power is to increase the coefficient of friction between the conveying elements and sugarcanes and lower the lifting angle of the conveying train. So we changed the material with different friction coefficient of the rolling fins of the cutting disc and altered the lifting angle of the conveying train g(show as Figure III). It was the initial simple trial to test the effect of improving conveying speed to the congestion, further measures would then be taken to achieve more if it successes.
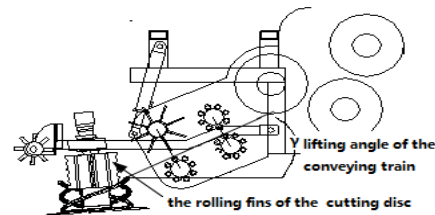

FIGURE III. STRUCTURE RETROFIT SCHEMATIC PLOT

VI. Field Experiment Method and Results Analysis

To verify increasing the conveying speed is a effective way to reduce the congestion rate with measures mentioned above, field experiment was carried out on a sugarcane field of a hilly area farm in Qinzhou, Guangxi province, China. The planting density of the sugarcane is 5.5 canes per meter. The sugarcane is NO.1 Guiliu, with average length 1800 mm, average stem diameter 17-23 mm, and straightness deviation less than 10 mm without obvious damage.

The harvester is a prototype model cooperative developed by our research team and an agricultural vehicle company, with engine power of 91kw, conveying channel width 315mm and wheel span 1200mm(Figure IV). In this experiment, the forward speed is set as 0.55 m/s. other instruments include a HM20 universal pressure sensor, a uT3004S data acquisition card, uTekOrb data collection processing and analysis software, a laptop computer and a tachometer.

FIGURE IV. THE PROTOTYPE HARVESTER FOR THIS EXPERIMENT

The experiment factors and levels are arranged as following Table IV and the indicator is conveying speed, as well as the congestion rate.

TABLE IV. EXPERIMENT FACTORS AND LEVELS

factors	levels			
	1	2	3	4
A:liftig angle of the conveying train $\gamma(^0)$	15	20	30	40
B:coefficient of friction	0.09	0.15	0.25	0.35

Combining four Different levels of the two factors can make sixteen different experiment groups .Each experiment group repeat 20 times to calculate the indicators: conveying speed and congestion rate. Results are shown as Table V.

TABLE V. EXPERIMENT RESULTS

Experiment group	Conveying speed(m/s)		Congestion rate
	average	Standard deviation	
A1B1	0.8	0.76	20%
A1B2	0.9	0.45	10%
A1B3	1.1	0.65	0
A1B4	1.23	0.23	0
A2B1	0.76	0.15	20%
A2B2	0.78	0.60	10%
A2B3	0.85	0.79	100%
A2B4	0.83	0.60	5%
A3B1	0.81	0.20	0
A3B2	0.79	0.09	0
A3B3	0.72	0.51	20%
A3B4	0.68	0.33	30%
A4B1	0.51	0.15	40%
A4B2	0.68	0.43	20%
A4B3	0.70	1.28	30%
A4B4	0.68	1.01	35%

From the results, the relationship between the two factors and the conveying speed can be clearly shown as following Figure V. In general, the conveying speed increases with the coefficient of the friction increased, and the lower the lifting angle of the conveying train the higher the conveying speed is.
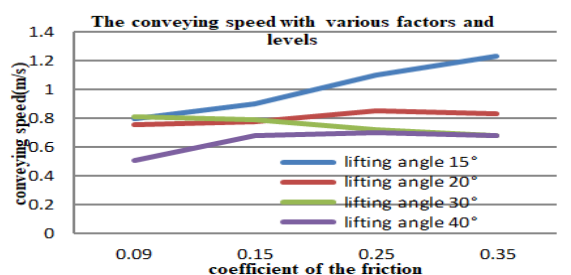

FIGURE V THE RELATIONSHIP BETWEEN THE CONVEYING SPEED AND VARIOUS FACTORS AND LEVELS

As to the relationship of the congestion rate and the conveying speed, Figure VI shows that generally the congestion rate is getting lower and lower as the conveying speed increases and it is better to keep the conveying speed at least higher than 1.1m/s.
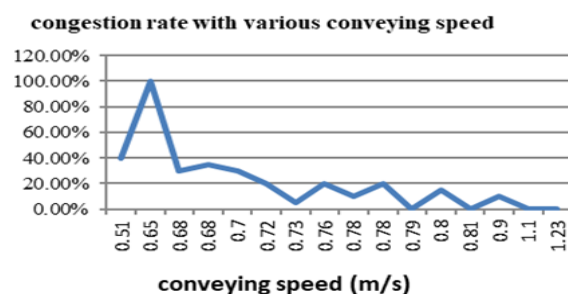

FIGURE VI THE RELATIONSHIP BETWEEN THE CONGESTION RATE AND THE CONVEYING SPEED

VII. CONCLUSION

This paper gives a new consideration to explain the harvester conveying congestion, putting forward the sugarcane growth randomness is the crucial factor to sugar canes stacking up when feeding, leading to harvester conveying congestion. For analysis to solve this problem in a way that could be generally applied, this paper introduces the queuing theory to establish a mathematical model of the process of the cane feeding through a harvester. Analysis of it shows that the sugarcanes conveying speed is the key factor to the rate of conveying congestion. Logistics simulation that followed shows that the congestion rate reduces from 20.3% to 6.28% when conveying speed increases from 0.8 m/s to 1.6 m/s with the conveying channel in 0.3 m width. According to this, harvester structure retrofit was carried on to improve the conveying speed without increase the driving power. The field experiment shows that the congestion rate is getting lower as the conveying speed increases and it is better to keep the conveying speed at least higher than 1.1m/s. This proves the correctness of the mathematic model based on queue theory and thus provides an effective new way to solve the harvester congestion problem.

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