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A Method of Using a Ground Fan to Remove Tobacco Stem Sticks During the Tobacco Production Process

Tao MA[1], Changqi DENG[2], Hua GAO[3]
Hongyun Honghe Tobacco(Group) Co., Ltd, Urumqi, Xinjiang, China

Abstract. Tobacco leaves contain a certain amount of stalk sticks after being shred, and most of these stalk sticks are removed in the silk line by local wind picker. However, in the actual production process, due to the influence of leaf silk moisture, flow rate and the cleaning degree of dust filter bag, the removal effect of stem air in leaf silk after selection is not stable. In order to solve this problem, the regression equations of dust removal speed of blade wire local air separator, frequency of high-speed belt conveyor and stalk removal rate of two key factors were established through experiments, so as to calculate the best dust removal speed of each brand during production and the dust removal speed of each brand under no-load condition. Then, the difference of these two dust removal speed was added to the best dust removal speed of each brand before production. The optimal no-load dust removal speed of each brand before production was obtained. At the same time, the linear regression equation of dust removal wind speed and dust removal fan frequency in no-load state of equipment was established through experiments. Before production, the optimal no-load dust removal wind speed was substituted into the equation, and finally the optimal theoretical frequency of dust removal fan was obtained. After the system error prevention detection, the theoretical frequency was automatically brought into the control system, so as to stabilize the stalk removal rate of local air separator of blade wire.

Keywords. local air separator, dust removal, wind speed motor frequency, no-load state, stick removal rate

1. Introduction

W. A. Shewhart [1] proposed that the quality of products is influenced by many unknown factors. Bartucca [2] believes that improper use of fertilizers can have a negative impact on tobacco quality. Tepecik[3] believes that there are certain differences in the quality of tobacco harvested at different times. Li Lin [4] proposed a tobacco moisture control method based on deep learning, which improved the quality of the product.

The leaf silk production process plays a central role in determining the inherent quality of cigarettes during the tobacco manufacturing process, as depicted in Figure 1. Among the key control parameters, the extent of stem tag removal is a critical indicator that significantly impacts the visual quality of cigarettes.

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[1] Corresponding Author: Tao Ma, Hongyun Honghe Tobacco(Group) Co., Ltd, 24791477@qq.com
[2] Changqi Deng, Hongyun Honghe Tobacco(Group) Co., Ltd, 383651350@qq.com
[3] Hua Gao, Hongyun Honghe Tobacco(Group) Co., Ltd, 44590458@qq.com

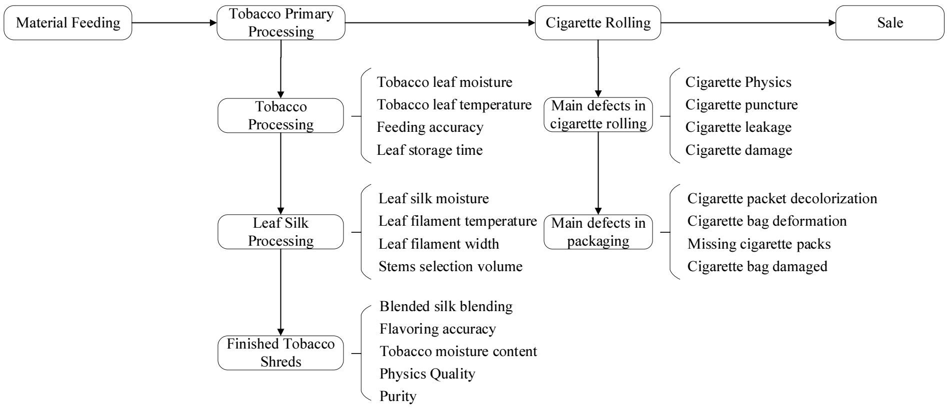

Figure 1. Key Process and Quality of Cigarette Processing

The presence of stem stickers in cut tobacco can lead to quality issues, such as compromised integrity of cigarette paper [5], thereby impinging on brand recognition. Additionally, stem stickers not only elevate the risk of market grievances but also exert a tangible influence on material consumption within the production process [6], particularly in terms of augmented blending weight of cut stems, heightened utilization of essence, and increased wastage of cut tobacco during the cigarette picking procedure. Therefore, ensuring a sustained and stable stem removal rate in the on-site wind classifiers for leaf silk is imperative for bolstering product quality stability and optimizing process efficiency.

2. Related Work

Currently, in the tobacco industry in China, there have been some studies focusing on enhancing the stem removal efficiency of on-site air separation machines for leaf tobacco. However, the practical application of these methods remains limited in scope. There are primarily two solutions available for addressing this technology: (1) Method for optimizing equipment parameters; (2) Method for stem removal of tobacco leaf in on-site air separation machine.

(1) Method for optimizing equipment parameters:

Kang et al. [7] conducted a rigorous analysis of the major process parameters of the equipment to assess their significance. Subsequently, a comprehensive factorial experiment was performed to identify the optimal control model by systematically exploring the effects of all factors. Through careful validation, the optimal parameter combination was successfully determined.

Wang et al. [8] conducted an orthogonal experiment to analyze the influence of various parameters of the air selection machine on cigarette quality indicators. Their findings demonstrated the significant impact of airflow velocity on the stem removal rate and other relevant factors.

Chen et al. [9] employed the orthogonal experimental method and determined that the optimal parameters for the air selection machine were a guide plate angle (scale) of 57, a fan frequency of 36Hz, and a side baffle height (scale) of 11. Under these conditions, they observed favorable effects in terms of stem removal for expanded tobacco and the removal of moist tobacco clusters.

Zhao et al. [10] installed a wind speed detection device in the air duct to establish an automatic closed-loop control system for wind speed regulation. This system was designed to mitigate the influences of factors such as equipment grid cleaning level, dust removal pipe cleaning cycle, dust accumulation in the pipe, and dust collector spraying frequency on the wind speed.

In overall assessment, the primary limitation of this approach manifests in its reliance on the unimpeded passage of leaf silk through the in-situ air separation machine, with the device performing a moderate level of stem removal to meet acceptable standards. However, from the perspective of stem removal effectiveness, the method struggles to sustain long-term stability in stem removal rate due to the susceptibility of the system to variations in airflow velocity resulting from fluctuations in the dust removal system.

(2) Method for stem removal of tobacco leaf in on-site air separation machine:

Yang Yaowei et al. [11] elucidated the necessity of incorporating the in-situ air separation process for leaf silk after drying.

Kang Jinling et al. [12] conducted a comprehensive analysis of the significant process parameters of the equipment, followed by a full factorial experiment to explore the main factors affecting the system. Subsequently, they established an optimal control model and validated it to determine the optimal parameter combination.

Wang et al. [13] developed an energy-efficient in-situ air selection system for leaf silk by implementing a local circulation of the process dust removal airflow, which was originally discharged into the dust removal room. This innovative approach effectively reduced the energy consumption of the system, contributing to improved sustainability and cost-effectiveness.

Xu Xiongwen [14] designed a new type of diamond-shaped combing rollers to enhance the impurity removal and separation efficiency in the flexible in-situ air selection machine for leaf silk. The innovative design resulted in improved purity of the waste material and reduced instances of misremoval of tobacco leaves, thereby enhancing the overall quality and yield of the processed leaf silk.

The use of on-site air separation for precise stem removal in cigarette manufacturing is characterized by its operational simplicity and high practicality. However, there is a lack of research documenting the system's methodology for achieving stable stem removal rates through self-learning and automatic adjustment of airflows.

3. Technology Program

The on-site air separation machine for leaf silk, as shown in Figure 2, has been facing the persistent issue of unstable stem removal rate. This can be attributed to two primary factors. Firstly, it is influenced by variations in processing standards, such as differences in moisture content and cutting width among different brands of leaf silk during the air selection process. In production, manual adjustment of equipment parameters based on empirical knowledge is often employed, which hampers the achievement of precise and stable control over the stem removal rate. Secondly, even when optimal air selection parameters for each brand of leaf silk are identified, the performance is affected by factors within the on-site air separation machine's dust removal system, including the cleanliness of the filter bags. Consequently, the negative pressure airflow velocity for dust removal gradually undergoes certain changes, causing fluctuations in the stem removal rate that cannot be maintained consistently over the long term.

To bridge this gap, we conducted a research study to investigate the method of utilizing an in-situ air separation machine for tobacco stem removal. Through rigorous experimentation and validation, we determined the optimal air velocity for efficient dust extraction and incorporated it into the self-learning and automated adjustment mechanism of fan frequency during equipment downtime. This adaptive control strategy effectively ensures the uniformity and reliability of stem removal in the on-site air separation system.

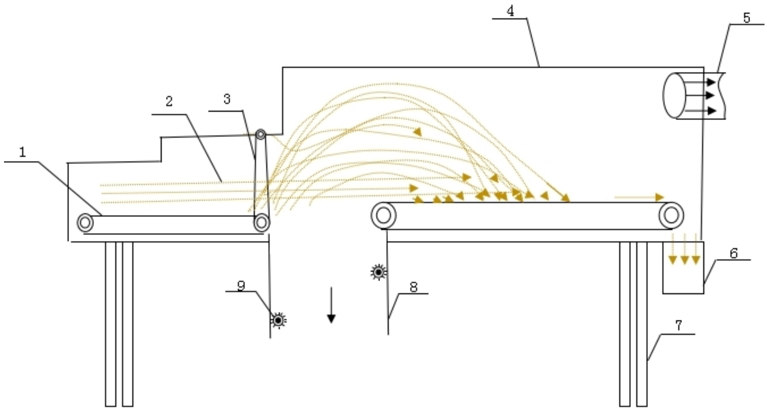

Figure 2. Schematic diagram of leaf silk on-site air separation machine

The numbers in Figure 2 are explained as follows.

1. High speed belt conveyor, 2. pipe tobacco, 3. driving system, 4. Hood, 5. Dust removal air duct 6. Cut tobacco discharge port, 7. Holder, 8. Stem stick removal port, 9. Throwing roller

3.1. Test Materials

In a factory located in northwest China, the FS418 type blade wire on-site air separator, manufactured by Kunchuan Company, is utilized. This air separator has a rated production capacity and air volume of 6000 Kg/h. The process for preparing and testing dried leaf silk samples is as follows:

(1) The discharge flap on the drying machine's discharge vibration slot is opened to discharge approximately 200 kilograms of leaf silk when the drying machine operates normally and the moisture content reaches the desired level.

(2) Leaf silk samples are collected by weighing 10 kilograms in each bag. A total of 11 bags are selected for DOE testing, which involves two factors, two levels, and three central points.

(3) Stem stick samples, previously prepared, are mixed with the leaf silk. Each bag of leaf silk receives an even distribution of 100 grams of stem stick samples.

(4) Following the experimental plan, the bags of samples are added evenly to the inlet equipment of the local air separation machine for leaf silk while the equipment is in operation. The number of removed stems from each group is recorded at the stem discharge port beneath the machine.

(5) Data analysis is performed.

(6) This method is employed to conduct wind selection tests for stem removal on other brands.

This systematic approach allows the factory to investigate the stem removal efficiency of the on-site air separation machine for different brands of leaf silk.

3.2. Test Process

3.2.1. DOE Design of Experiments Analysis

Through the utilization of the DOE (Design of Experiments) methodology, a parameter optimization test was conducted for two pivotal factors: the dedusting wind velocity and the frequency of the high-speed belt motor. The dedusting wind velocity was examined at high (17.5 m/s), low (14.5 m/s), and central (16.0 m/s) levels, while the frequency of the high-speed belt conveyor was scrutinized at high (39.00 Hz), low (37.50 Hz), and central (38.25 Hz) levels. The stem removal test results corresponding to each level are delineated in Table 1.

Table 1 Design of experiments

Standard sequence	Run sequence	Center point	Block group	Dust removal wind speed (m/s)	High speed belt conveyor frequency (HZ)	Number of stem labels removed (g)
1	1	1	1	14.5	37.5	25.54
2	2	1	1	17.5	37.5	23.41
3	3	1	1	14.5	39	16.81
5	4	0	1	16	38.25	18.99
7	5	0	1	16	38.25	19.08
6	6	0	1	16	38.25	19.17
4	7	1	1	17.5	39	14.81

Table 2 Test Result Data

Term	Influence	coefficient	Coefficient Standard error	T	P	S	R-Sq	S-Sq (adjust)
Constant	-	20.142	0.04126	488.23	0.00	0.082512	99.95%	99.95%
Dust removal wind speed	-2.065	-1.032	0.04126	-25.03	0.00			
High speed belt conveyor frequency	-8.665	-4.332	0.04126	-105.01	0.00			

Based on the data presented in Table 2, it is observed that the P-values of the intercept term and the two factors are all below the significance threshold of 0.05, indicating a statistically significant regression model and significant effects of the factors. The coefficients of determination (R-squared) and adjusted R-squared values are close to 1, implying a strong goodness of fit and demonstrating the suitability of the experimental results for practical applications in production.

Table 3 Test Result Coefficients

Term	Coefficient
Constant	252.113
Dust removal wind speed	-0.688333
High speed belt conveyor frequency	-5.77667

Result Analysis: Upon analyzing the results depicted in Table 3, the multiple regression equation is formulated as follows: the stem removal amount can be predicted by the equation stem removal amount = 252.113 - 0.688333 × dedusting wind speed - 5.77667 × high-speed belt conveyor frequency.

3.2.2. Optimal Dust Removal Wind Speed for Each Brand of Blade Wire

The experimental findings reveal the absence of an interaction effect between the high-speed belt motor frequency and the dedusting wind speed. Ideally, in a controlled production environment, maintaining optimal values for the high-speed belt motor frequency and dedusting wind speed is critical to ensure a consistent removal rate of stem tags. However, in practical production scenarios, while the operating speed of the high-speed belt conveyor remains relatively stable due to fewer influencing factors, the dedusting wind speed is prone to fluctuations due to variations in leaf silk flow, the cleanliness of the deduster's filter bag, and adjustments in the air valve opening, among other factors.

To address this issue, a fixed high-speed belt conveyor frequency of 38.0Hz, determined through preliminary tests, is employed. Utilizing the multiple regression equation, the maximum expected stem removal amount for each brand is inputted to calculate the optimal dedusting wind speed for production. Simultaneously, under the same operating conditions, the dedusting wind speed of the equipment in the no-load state is measured and calculated. The resulting wind speed difference (di) between the production and no-load operating states is considered a constant. Prior to commencing production, the optimal no-load dedusting wind speed for each brand is determined by adding di to the optimal dedusting wind speed determined before production. The outcomes of these calculations are presented in Table 4.

Table 4 Wind speed difference between equipment production and no-load state

brand	Maximum rejection amount of stem sign (g)	High speed belt conveyor frequency (HZ)	Production optimal dust removal wind speed (m/s)	Optimal no-load dust removal wind speed (m/s)	Wind speed difference (m/s)
A	21.0	38.0	16.85	20.10	3.25
B	21.5	38.0	16.13	19.88	3.75
C	21.9	38.0	15.54	19.93	4.39

3.3. Self Learning Function for Optimal Dust Removal Frequency

The primary method for regulating the dust removal airflow velocity under unaltered production conditions involves adjusting the rotational frequency of the dust removal fan. The empirical data analysis establishes *a* regression equation correlating the dedusting airflow velocity with the fan frequency.

$$y_{Dust\ removal\ wind\ speed} = a + b \times x_{Fan\ frequency} \tag{1}$$

Among them, y is positively correlated with x, and the program control system can complete corresponding calculations as needed during each no-load operation state of the equipment.

3.3.1. Calculation Method for Optimal Frequency of Dust Removal Fan

By employing preset values through the software program, the frequency x_i of various dust removal fans is automatically adjusted under the equipment's idle state, and subsequently, the total average dust removal fan frequency x is calculated. Using the feedback value y_i from the anemometer installed on the dust removal pipe, the average wind speed (y_i) corresponding to different dust removal fan frequencies within a specific time period t is determined, and the average total dust removal wind speed (y) is computed. Finally, the regression equation's slope b and intercept a are calculated to characterize the relationship in the unloaded state.

$$b = \frac{\sum_{i=1}^{n} x_i \overline{y_i} - n\overline{x}\overline{y}}{\sum_{i=1}^{n} x_i^2 - n\overline{x}^2} \tag{2}$$

$$a = \overline{y} - b\overline{x} \tag{3}$$

Given the consistent process flow and stable equipment operation at different time intervals, along with the fixed difference d_i between the optimal dust removal wind speed and the no-load dust removal wind speed, d_i can be considered a constant across various brands. By adding the optimal dust removal wind speed during production to the constant d_i, the optimal dust removal wind speed under the no-load state for each brand can be determined. Subsequently, the obtained intercept a, slope b, and the optimal dust removal wind speed under the no-load state are incorporated into the equation to calculate the frequency of the dust removal fan during production. The test results are presented in Table 5.

Table 5 Test results of dust removal wind speed and dust removal fan frequency

Group	x_i	$\overline{y_i}$	a	b	R	S
1	34.0	13.6	-24.0	1.10	0.99	0.073
2	34.2	13.9				
3	34.4	14.0				
5	34.6	14.2				
6	34.8	14.5				
7	35.0	14.6				
8	35.2	14.8				
9	35.4	15.1				
10	35.6	15.3				
11	35.8	15.6				
12	36.0	15.9				
	$\overline{x}$=35.0	**$\overline{y}$=14.68**				

Result analysis: The linear regression equation between the dust removal wind speed obtained from the experiment and the frequency of the dust removal fan is: y dust removal *wind speed=-24.0+1.10x* fan frequency. Calculate the optimal frequency of dust removal fans for each brand based on this, and the calculation results are shown in Table 6.

Table 6 Optimal Dust Removal Fan Frequency

Group	Production optimal dust removal wind speed (m/s)	Wind speed differenced (m/s)	Optimal no-load dust removal wind speed (m/s)	$X_{\text{Fan frequency}}$ (HZ)
A	16.85	3.25	20.10	40.1
B	16.13	3.75	19.88	39.9
C	15.54	4.39	19.93	39.9

Prior to production, the optimal no-load dust removal wind speed is utilized to calculate the optimal theoretical frequency of the dust removal fan using the provided equation. After conducting system error prevention detection, this calculated theoretical frequency is automatically integrated into the control system to ensure the stable removal of stem tags by the blade and wire local air separator.

3.4. Chapter Summary

This section primarily focuses on the method of using an in-situ air separation machine to remove tobacco stems, and it presents the design of multiple experiments to validate the optimal parameters for the air separation machine.

4. Application Examples

After the practical application of this research achievement, a statistical analysis was conducted on the stem removal quantity during a 1.5-hour production period for three different brands, covering the period from August to December 2022. The average range of stem removal quantity for each brand was found to be 0.37 kg, as shown in Table 7.

Table 7 Actual production data

Month	Batch	Number of Stem Labels Removed(Kg)		
		A (grade)	B (grade)	C (grade)
8	5	26.21	24.42	23.16
	6	26.35	24.48	23.19
	7	26.09	24.17	23.25
	8	26.37	24.51	23.09
9	9	26.28	24.53	22.99
	10	26.05	24.21	23.17
	11	26.53	24.37	23.04
	12	26.54	24.33	23.12
10	13	26.75	24.20	23.07
	14	26.55	24.22	23.11
	15	26.40	24.37	23.25
	16	26.53	24.33	23.01
11	17	26.62	24.50	23.25
	18	26.34	24.45	23.31
	19	26.65	24.41	23.26
	20	26.20	24.31	23.28
12	21	26.34	24.33	23.09
	22	26.30	24.36	23.00

	23	26.48	24.19	22.98
	24	26.51	24.54	23.16
range		0.4	0.37	0.33
Average range			0.37	

5. Conclusion

With the growing emphasis on high-quality cigarette production, there is an increasing need for efficient stem removal in on-site leaf silk air separation machines. To address this demand, a novel control method has been developed, which ensures long-term stability in stem removal rates and enhances overall product quality. This method holds significant potential for widespread adoption and practical implementation in the parameter control of local air separators used in leaf wire processing.

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