Research on the critical equipment parameter control technology of slim cigarette rod forming

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Abstract: In order to obtain the optimal control of the parameters of the critical equipment for the formation of a slim cigarette rod. In this study, the loose-end rate and weight stability are taken as the measurement indicators. According to the five factors that affect the control parameters of the critical equipment of tobacco forming, the “Uniform Design Method” is used to set up different control parameter combinations. The stepwise function is used to analyze the quadratic polynomial stepwise regression analysis, and the control parameter model is established and verified and optimized. The results show that the negative pressure of the suction chamber is 90Mbar, the proportion coefficient of the needle roller is 78%, the thickness of the block above the cleaver disc (the rail of the suction) is 2.5mm, the gap between the wire pressing wheel and the rail of the cigarette gun is 4.3mm, and the height of the cigarette tongue outlet is 4.3mm. The optimal range of the forming parameters of the cigarette rod can be obtained, which can effectively reduce the loose-end rate of the slim cigarette rod and improve the stability of the cigarette weight.

1. Introduction
The forming technology of the cigarette rod is the critical technology of the cigarette machine. How to improve the forming technology of cigarette rod, ensure the stable supply of tobacco, make the filling of tobacco rod even and full, and improve the quality of cigarette rolling has always been the breakthrough direction of the development and research of high-speed cigarette machine. At present, the development of cigarette forming technology is mainly reflected in 1. Significant technological innovation has been made in critical technologies such as cigarette stem screening, one cut two cut tobacco, dual fluidization tank [1,2]. 2. Li Wei et al.[3] improved the rail of the suction belt of ZJ17 Windlass. After improvement, the fluctuation range of loose-end rate can be reduced to 0.08% - 0.12%, the short-term standard deviation of cigarette quality can be reduced to 11.4 mg, and the long-term standard deviation of cigarette quality can be reduced to 4.2 mg. 3. Huang Ligang [4] improves the material, structure, and working face of the rail of the ZJ19 air chamber to effectively solve the problem of loose-end and sizeable standard deviation; 4. Li Shaoping and others [5] improve the layout mode, section shape, and base material of the rail of the passim windlass to improve the adsorption of the tobacco and solve the problem of tobacco slipping. It avoids the deviation of the tight end position and the change of the shape of the tobacco bundle in the high-speed movement; 5. Ding Shihu [6] reduces the scrap rate of a single cigarette box by introducing a blower at the outlet of the small fan, expanding
the area of the air cavity hole; 6. Shi Xiao [7] provides enough negative pressure for the tobacco bundle in the trimming process of the leveler by adding the auxiliary negative pressure device of the air chamber, to ensure that the tight end position does not shift. Thus, the loose-end rate and the standard deviation of single cigarette weight are reduced. However, the above technical research mainly focuses on the solution and breakthrough of technical points and problem points. Most of the further optimization of the system has not been carried out in-depth research. In addition, most of the technologies reported in the literature are based on traditional cigarette machine equipment, and there is almost no research report on the improvement design of the parameters of cigarette forming equipment of slim cigarette machine. Therefore, taking the loose-end rate and weight stability as the measurement indicators, aiming at the influencing factors of critical equipment control parameters (negative pressure of the suction chamber, proportional coefficient of needle roller, the thickness of the block above the cleaver disc (the rail of the suction), the gap between the wire pressing wheel and the rail of the cigarette gun, and the height of the cigarette tongue outlet). While the "uniform design method" is adopted to set different control parameter combinations, the stepwise function is used to analyze the quadratic polynomial step-by-step regression. The control parameter model is established, verified, and optimized.

2. Materials and Methods

2.1. Uniform design methods

Adopt the "uniform design" method, set the parameters of the negative pressure of the suction chamber, the proportion coefficient of needle roller, the thickness of the block above the cleaver disc (the rail of the suction), the gap between the wire pressing wheel and the rail of the cigarette gun, and the height of the cigarette tongue outlet. See table 1 for the uniform design of different critical equipment parameters.

| No. | X1-The negative pressure of the suction chamber(Mbar) | X2-The proportion coefficient of needle roller(%) | X3-The thickness of the block above the cleaver disc(mm) | X4-The gap between the wire pressing wheel and the rail of the cigarette gun(mm) | X5-The height of the cigarette tongue outlet(mm) |
|-----|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 1   | -88                             | 78                              | 2.6                              | 4.3                              | 4.3                              |
| 2   | -90                             | 77                              | 2.5                              | 4.32                             | 4.3                              |
| 3   | -89                             | 80                              | 3                                | 4.25                             | 4.32                             |
| 4   | -90                             | 79                              | 2.8                              | 4.3                              | 4.28                             |
| 5   | -86                             | 78                              | 3.5                              | 4.3                              | 4.28                             |
| 6   | -85                             | 77                              | 2.5                              | 4.28                             | 4.32                             |
| 7   | -88                             | 76                              | 2.9                              | 4.28                             | 4.25                             |
| 8   | -89                             | 75                              | 3.2                              | 4.3                              | 4.35                             |
| 9   | -87                             | 79                              | 2.7                              | 4.35                             | 4.3                              |
2.2 Experiment scheme and design

2.2.1. Experiment conditions and instruments:
1) Test brand: A tobacco; 2) winding-up equipment: PROTOS 2C; 3) Testing instrument: French sodium 74lab314 Integrated Test Station; 4) Specifications of test cigarettes: A cigarette, length ((70.0 ± 30.0) ± 0.5) mm, circumference (17.00 ± 0.20) mm, weight (11.0 ± 0.20) g / 20, draw resistance (1270 ± 250) Pa; 5) Material technical requirements: 120 / 16.9 filter rod (0cu3500pa), wood pulp cigarette paper (T) 32g * 37mm * 5000m (straight 50), tipping paper of A (version 7.0) 38.5g * 70mm * 2500m, holder adhesive; 6) Test requirements: put the sample in the environment of (25 ± 2) ℃, (62 ± 5)% for 6 hours, and then test the physical properties of the sample according to the specified method requirements.

2.2.2. Test method:
When sampling each sample for the test, it is necessary to wait for the equipment to operate normally for 15 minutes, and then take one group every 10 minutes, a total of 10 groups are taken, and 20 samples are taken from each group. Simultaneously, the loose-end rate(ykt) data shall be recorded, and the standard deviation of weight(yzp) on each group of samples shall be measured and counted by the Integrated Test Station.

3. results and analysis

3.1. test results
See table 2 for test process parameters.

| No. | X1 | X2 | X3 | X4 | X5 | ykt | yzp |
|-----|----|----|----|----|----|-----|-----|
| 1   | -88| 78 | 2.6| 4.3| 4.3| 1.03| 14.78|
| 2   | -90| 77 | 2.5| 4.32|4.3| 0.95| 14.22|
| 3   | -89| 80 | 3  | 4.25|4.32|7.25|17.3 |
| 4   | -90| 79 | 2.8| 4.3 |4.28|2.55|16.25|
| 5   | -86| 78 | 3.5| 4.32|4.28|4.23|16.1 |
| 6   | -85| 77 | 2.5| 4.28|4.32|3.58|15.56|
| 7   | -88| 76 | 2.9| 4.28|4.25|6.88|17.12|
| 8   | -89| 75 | 3.2| 4.3  |4.35|3.78|15.36|
| 9   | -87| 79 | 2.7| 4.35|4.3 |5.64|16.77|

Make a linear transformation for the independent variable, and map the value to [0.1,0.9] interval according to formula \(X_i = \frac{x-x_{min}}{x_{max}-x_{min}} \times 0.8\), as shown in table 3.

| No. | X1 | X2 | X3 | X4 | X5 | ykt | yzp |
|-----|----|----|----|----|----|-----|-----|
| 1   | 0.58| 0.58| 0.18| 0.5 |0.5| 1.03| 14.78|
| 2   | 0.9 | 0.42| 0.1 |0.66|0.5| 0.95| 14.22|
| 3   | 0.74| 0.9 | 0.5 |0.1 |0.66|7.25|17.3 |
| 4   | 0.9 | 0.74| 0.34|0.5 |0.34|2.55|16.25|
| 5   | 0.26| 0.58| 0.9 |0.66|0.34|4.23|16.1 |
3.2. Establishment of the quadratic polynomial stepwise regression model

According to the linear changes and response variables, the stepwise function is used to analyze the quadratic polynomial stepwise regression on the MATLAB platform. The model and parameters are as follows:

\[
1: y = 7.5961 x_4 + 27.7631 x_4 x_1 + 5.9001 x_4 x_2 + 7.1401 x_4 x_3 + 16.1991 x_4 x_5 + 6.8810 x_1 + 15.5611 x_2 + 3.5812 x_3 + 17.1213 x_5, \\
RMSE = 0.434678, \text{Adj } R^2 \text{ sq } = 0.964052, F = 36.7576, p = 0.0267129.
\]

p < 0.05 It shows that the model is independent and significant.

\[
2: y = 16.1991 x_4 x_1 + 5.9001 x_4 x_2 + 7.1401 x_4 x_3 + 5.2281 x_1 x_2 + 6.3651 x_4 x_5, \\
RMSE = 0.339108, \text{Adj } R^2 \text{ sq } = 0.895902, F = 14.7702, p = 0.0252735.
\]

p < 0.05 It shows that the model is independent and significant.

3.3. model analysis

It can be seen from model 1 that there is the interaction term of X1 and X4, X2 and X4, X3 and X5, X1 and X3 in the experimental range; The interaction term of X1 and X3, and the quadratic term of X4 have a positive effect on the loose-end rate, while the linear term of X4, the interaction term of X1 and X4, X2 and X4, X3 and X5 have a negative effect on the loose-end rate.

In order to investigate the influence of various factors on the loose-end rate, the negative pressure of the suction chamber, the proportional coefficient of needle roller, the thickness of the block above the cleaver disk (the rail of the suction), the gap between the wire pressing wheel and the rail of the cigarette gun and the height of the cigarette tongue outlet are used to calculate the derivation:

\[
\frac{\partial y}{\partial x_1} = 20.5531 x_3 + 12.5991 x_4, \\
\frac{\partial y}{\partial x_2} = 11.2411 x_4, \\
\frac{\partial y}{\partial x_3} = 20.5531 x_1 + 14.5441 x_5, \\
\frac{\partial y}{\partial x_4} = 114.013 + 55.5261 x_4 + 12.5991 x_1 + 11.2411 x_2, \\
\frac{\partial y}{\partial x_5} = 114.5441 x_3.
\]

In Formula (1), It shows that the influence of negative pressure of suction chamber on the loose-end rate depends on the ratio of the thickness of the block above the cleaver disc to the gap between the wire pressing wheel and the rail of the cigarette gun.

When \( \frac{\partial y}{\partial x_1} > 0 \), the influence of the negative pressure of the suction chamber on the loose-end rate is positive.

When \( \frac{\partial y}{\partial x_1} < 0 \), the influence of the negative pressure of the suction chamber on the loose-end rate is negative.

|   | 6   | 0.1 | 0.42 | 0.1  | 0.34 | 0.66 | 3.58 | 15.56 |
|---|-----|-----|------|------|------|------|------|-------|
| 7 | 0.58| 0.26| 0.42 | 0.34 | 0.1  | 6.88 | 17.12|
| 8 | 0.74| 0.1  | 0.66 | 0.5  | 0.9  | 3.78 | 15.36|
| 9 | 0.42| 0.74 | 0.26 | 0.9  | 0.5  | 5.64 | 16.77|
When \( \frac{\partial y_{kt}}{\partial x_1} = 0 \), the negative pressure of the suction chamber does not affect the loose-end rate.

In Formula (2), It shows that the influence of the proportion coefficient of needle roller on the loose-end rate is negative, and the influence amplitude increases with the increase of the gap between the wire pressing wheel and the rail of the cigarette gun.

In Formula (3), It shows that the influence of the thickness of the block above the cleaver disc on the loose-end rate depends on the ratio of the negative pressure of the suction chamber to the height of the cigarette tongue outlet.

When \( \frac{\partial y_{kt}}{\partial x_3} > 0 \), the influence of the thickness of the block above the cleaver disc on the loose-end rate is positive.

When \( \frac{\partial y_{kt}}{\partial x_3} < 0 \), the influence of the thickness of the block above the cleaver disc on the loose-end rate is negative.

When \( \frac{\partial y_{kt}}{\partial x_3} = 0 \), the thickness of the block above the cleaver disc does not affect the loose-end rate.

In Formula (4), It shows that the influence of the gap between the wire pressing wheel and the rail of the cigarette gun on the loose-end rate is very complex, which depends on the specific value of the negative pressure of the suction chamber, the proportion coefficient of needle roller and the gap between the wire pressing wheel and the rail of the cigarette gun.

When \( \frac{\partial y_{kt}}{\partial x_4} > 0 \) The influence of the gap between the wire pressing wheel and the rail of the cigarette gun on the loose-end rate is positive.

When \( \frac{\partial y_{kt}}{\partial x_4} < 0 \) The influence of the gap between the wire pressing wheel and the rail of the cigarette gun on the loose-end rate is negative.

When \( \frac{\partial y_{kt}}{\partial x_4} = 0 \) The gap between the wire pressing wheel and the rail of the cigarette gun does not affect the loose-end rate.

In Formula (5), It shows that the influence of the height of the cigarette tongue outlet on the loose-end rate is negative, and the influence amplitude increases with the increase of the thickness of the block above the cleaver disc (the rail of the suction).

It can be seen from model 2 that there is the interaction term of \( X_1 \) and \( X_3 \), \( X_1 \) and \( X_4 \), \( X_4 \) and \( X_5 \) in the experimental range.

The interaction terms of \( X_1 \) and \( X_3 \), the quadratic term of \( X_4 \) have positive effects on the standard deviation of weight, while the interaction terms of \( X_1 \) and \( X_4 \), \( X_4 \) and \( X_5 \), the quadratic term of \( X_3 \) have negative effects on the standard deviation of weight.

In order to investigate the influence of various factors on the standard deviation of weight, the negative pressure of the suction chamber, the proportional coefficient of needle roller, the thickness of the block above the cleaver disk (the rail of the suction), the gap between the wire pressing wheel and the rail of the cigarette gun and the height of the cigarette tongue outlet are used to calculate the derivation:

\[
\frac{\partial y_{zp}}{\partial x_1} = 7.1401 \times X_3 + 5.2281 \times X_4
\]

\[
\frac{\partial y_{zp}}{\partial x_2} = 0
\]
In Formula (6), it shows that the influence of the negative pressure of the suction chamber on the standard deviation of weight depends on the ratio of the thickness of the block above the cleaver disc to the gap between the wire pressing wheel and the rail of the cigarette gun.

When \( \frac{\Theta yzp}{\Theta x1} > 0 \), the influence of the negative pressure of the suction chamber on the standard deviation of weight is positive.

When \( \frac{\Theta yzp}{\Theta x1} < 0 \), the influence of the negative pressure of the suction chamber on the standard deviation of weight is negative.

When \( \frac{\Theta yzp}{\Theta x1} = 0 \), the negative pressure of the suction chamber does not affect the standard deviation of weight.

In Formula (7), it shows that the proportion coefficient of needle roller does not affect the standard deviation of weight.

In Formula (8), it shows that the influence of the thickness of the block above the cleaver disc on the standard deviation of weight depends on the ratio of the negative pressure of the suction chamber to the block above the cleaver disc.

When \( \frac{\Theta yzp}{\Theta x3} > 0 \), the influence of the thickness of the block above the cleaver disc on the standard deviation of weight is positive.

When \( \frac{\Theta yzp}{\Theta x3} < 0 \), the influence of the thickness of the block above the cleaver disc on the standard deviation of weight is negative.

When \( \frac{\Theta yzp}{\Theta x3} = 0 \), the thickness of the block above the cleaver disc does not affect the standard deviation of weight.

In Formula (9), it shows that the influence of the gap between the wire pressing wheel and the rail of the cigarette gun on the standard deviation of weight is very complex, which depends on the specific values of the negative pressure of the suction chamber, the gap between the wire pressing wheel and the rail of the cigarette gun and the height of the cigarette tongue outlet.

When \( \frac{\Theta yzp}{\Theta x4} > 0 \), the gap between the wire pressing wheel and the rail of the cigarette gun on the standard deviation of weight is positive.

When \( \frac{\Theta yzp}{\Theta x4} < 0 \), the gap between the wire pressing wheel and the rail of the cigarette gun on the standard deviation of weight is negative.

When \( \frac{\Theta yzp}{\Theta x4} = 0 \), the gap between the wire pressing wheel and the rail of the cigarette gun does not affect the standard deviation of weight.

In Formula (10), the results show that the influence of the height of the cigarette tongue outlet on
the standard deviation of weight is negative, and the influence amplitude increases with the increase of the gap between the wire pressing wheel and the rail of the cigarette gun.

3.4. model validation

3.4.1. Model reliability validation
The middle values of variables X1, X2, X3, X4 and X5 in the experimental range, i.e. X1:88 (0.58), X2:77(0.42), X3:3(0.5), X4:4.3(0.50) and X5:4.3(0.50), were taken for validation experiment. The results are shown in Table 4.

| Item               | X1(Mbar) | X2(%) | X3(mm) | X4(mm) | X5(mm) | ykt   | yzp   |
|--------------------|----------|-------|--------|--------|--------|-------|-------|
| Model output       | -88      | 77    | 3      | 4.3    | 4.3    | 3.840 | 16.023|
| actual values      | -88      | 77    | 3      | 4.3    | 4.3    | 3.69  | 16.44 |
| Relative difference % |         |       |        |        |        | 3.99  | 2.57  |

The relative difference between the experimental results is less than 5%, which shows that the model is reliable.

3.4.2. Model optimization validation
the loose-end rate: within 1% and the standard deviation of weight: within 15. Use the established model to calculate and get the optimization results, as shown in Table 5.

| No. | X1(Mbar) | X2(%) | X3(mm) | X4(mm) | X5(mm) | ykt   | yzp   |
|-----|----------|-------|--------|--------|--------|-------|-------|
| 1   | 0.9      | 0.58  | 0.1    | 0.5    | 0.5    | 0.96  | 14.35 |

See Table 6 for the conversion of independent variables to the original values.

| No. | X1(Mbar) | X2(%) | X3(mm) | X4(mm) | X5(mm) | ykt   | yzp   |
|-----|----------|-------|--------|--------|--------|-------|-------|
| 1   | 90.00    | 78.00 | 2.50   | 4.30   | 4.30   | 0.96  | 14.35 |

The parameters optimized by the model can significantly improve the stability of cigarette rod forming control of slim cigarettes, the stability of cigarette weight, and the loose-end rate.

4. Conclusion and Discussion
The optimization parameters of cigarette forming equipment are determined as follows: The negative pressure of suction chamber is 90 Mbar, The proportion coefficient of needle roller is 78%, The thickness of the block above the cleaver disc is 2.5 mm, The gap between the pressing wheel and the rail of the cigarette gun is 4.3 mm, and The height of the cigarette tongue outlet is 4.3 mm, which can effectively reduce the loose-end rate of the slim cigarette rod and improve the stability of the cigarette weight.

This research is mainly based on the work carried out under the special topic "tobacco rod forming and rolling parameter control technology" under the route of "Research on rod forming and drilling technology of slim cigarette". Taking the standard deviation of weight and the loose-end rate as the measurement indicators, the critical parameters, and control range of tobacco rod forming were determined by single-factor analysis and uniform test design, which improved the uniformity of tobacco
filling and solved the displacement of the tight end in tobacco rod conveying and cutting process.

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