The segmentation method model based on cigarette density for burning cone drop rate prediction of super slim cigarettes

J Li¹, W L Lian¹, Y B Qu¹, L Chen¹, Z G Wang¹, J R Huang¹, Y Zhao¹, Z Y Zhu¹, W Liu¹, Q Chen¹, Z W Sun¹, S T Wang¹ and C Tan¹,²

¹ Technology Center of China Tobacco Hunan Industrial Co., Ltd., Changsha, Hunan 410007, China
² E-mail: tanch1004@hngytobacco.com

Abstract. The phenomenon of burning cone drop is a serious quality defect in super slim cigarettes. In order to monitor the burning cone drop, a segmentation model conveniently and effectively about cigarette packing density was established and used for predicting the burning cone drop rate. The method is a non-destructive testing (NDT), which is applied by using cigarette density and its change rate.

The model of cigarette density segmentation method is based on a straight line \( \rho = A \rho' + B \) in the Cartesian coordinate system with abscissa \( \rho' \) and ordinate \( \rho \). The straight line split the coordinate system into two regions. By measuring the density of the super slim cigarettes, the position of the point \( (\rho', \rho) \) can be determined, then the burning cone drop tendency can be predicted.

When verifying the accuracy of the model, it is found that the predicted value and the measured value are basically near the 1:1 line, the coefficient of determination \( (R^2) \) and the index of agreement (D index) between predicted and observed values are 0.98 and 0.99 respectively, and the normalized root mean square error (nRMSE) is 11.8%. The coefficient of variation of the predicted burning cone drop rate is 6.5% for 10 consecutive replicates.

The cigarette density segmentation method model is suitable for predicting burning cone drop of the super slim cigarette samples with varying packing densities or cut tobacco distribution. The model has a good effect on the burning cone drop prediction under certain conditions, and it has an important guiding significance for super slim cigarette production and quality inspection.

1. Introduction

The burning cone drop will interrupt the smoking and reduce the consumer's recognition of cigarette brands, it may also cause fire hazards and harm consumers' interests. In view of the common phenomenon of burning cone drop of super slim cigarettes, more and more tobacco companies will bring burning cone drop into the field of cigarette quality control in the future. There have been some literatures about the factors affecting the falling of the burning cone, such as the structure of tobacco [1], the burning speed of cigarette paper [2], the width of cut tobacco [3-4], and the moisture content in cut tobacco [5-6], etc. These factors essentially change the force on the burning cone that affects the burning cone drop of the cigarette, the filling state of cut tobacco in cigarette is also an important way to change the force. At present, there are some studies on the influences of tobacco filling state on the quality of cigarette, such as the influence of different ecreteur discs on cigarette density [7-8], the influence of ecreteur discs on the rate of cigarette loose end [9], and the influence of standard...
deviation of cigarette density on the amount of tobacco loss from cigarette end [10]. However, it is rare to see any report on how the filling state of cut tobacco affects the burning cone drop of the super slim cigarette.

In the existing test methods for the burning cone drop, both manual method and instrument method need to ignite the cigarettes, that is destructive to the sample. If a nondestructive testing method is developed to obtain the burning cone drop rate, so that subsequent tests can be carried out with the same samples, it is of great significance to ensure the consistency of the testing samples.

The main work of this thesis is to create a model to find the internal relationship between the super slim cigarette burning cone drop and the filling state of cut tobacco. The filling state of cut tobacco is reflected in two aspects, one is the filling amount and the other is the distribution in cigarette. The validity of the model is well verified by samples with different packing density and distribution of cut tobacco by adjusting the individual cigarette weight and replacing different ecreteur discs. The segmentation method model has the specificities as follow: 1. For cigarette that only change the filling amount or distribution of cut tobacco, the burning cone drop rate can be determined by cigarette density data without destroying cigarette samples, thus realizing the conversion from destructive detection to nondestructive detection; 2. The burning cone drop detection device can only obtain the first position of cone drop, while the segmentation method model can obtain every possible position on the whole cigarette, and the position accuracy can reach up to 1 mm; 3. it is helpful to take targeted measures to improve the distribution of cut tobacco and reduce the burning cone drop rate; 4. This technology can be integrated into an on-line detection device and installed on the cigarette production line. It can detect and eliminate cigarettes with high drop rate risk in time, it is beneficial to improving the quality of cigarette products.

2. Materials and methods

2.1. Materials and instruments

2.1.1. Experimental materials. Super slim cigarette samples of a certain brand on the market; samples with different packing density and distribution of cut tobacco; China Tobacco Hunan Industrial Co., Ltd. The production process and cigarette materials and tobacco blend of testing samples are the same. All cigarette samples in this research were conditioned and tested according to the temperature and humidity conditions specified in ISO 3402:1999[11].

2.1.2. Instruments and equipment. Electronic analytical balance: XP404S (sensitivity: 0.0001 g), Mettler Toledo Company, Switzerland; Microwave density moisture analyzer, MW3220 type, TEWS Company, Germany; Burning cone drop detection device: developed by the laboratory; Cigarettes maker: PROTOS70, HAUNI Company, Germany.

2.2. Experimental method.

2.2.1. Preparation of testing samples.
(1) Preparation of control samples: 100 super slim cigarettes of a certain brand produced daily were randomly selected as control samples. The allowable range of individual cigarette weight was 0.545 g±0.06g, according to the corresponding cigarette technical requirements, and the ecreteur discs used was 0# in Table 1.
(2) Preparation of samples with different packing density of cut tobacco: adjust the individual cigarette weight to prepare samples with different packing density of tobacco. The ecreteur discs used was 0# in Table 1. By adjusting its height, five group samples with different target individual cigarette weight (0.500g, 0.530g, 0.560g, 0.590g, 0.620g) were trial-produced and selected according to the target weight ±0.010g. 20 cigarettes in a group were tested for density and 100 cigarettes in a group for burning cone drop.
(3) Preparation of samples with different distribution of cut tobacco: replacing different types of ecrêteur discs, as shown in Table 1, during cigarette rolling process, samples with same individual cigarette weight and different cut tobacco distribution were prepared.

Table 1. The cut tobacco distribution sample.

| Sample number | Pocket width(mm)×pocket depth(mm)×number of ecrêteur | Notes |
|---------------|-----------------------------------------------------|-------|
| 0#            | 24×2.5×6                                             | 6 pockets with identical depth |
| 1#            | 16×2.5×6                                             | 6 pockets with identical depth |
| 2#            | 0                                                    | No pocket |
| 3#            | 16×(2.5+2.0)×3                                       | 3 deep and 3 shallow pockets alternated |
| 4#            | 16×(2.5+2.2)×3                                       | 3 deep and 3 shallow pockets alternated |
| 5#            | 16×2.3×6                                             | 6 pockets with identical depth |
| 6#            | 16×2.5×6+4×1.5×6                                     | 6 big and 6 small pockets alternated |

The samples were selected according to the individual cigarette weight of 0.545 g±0.010g. 20 cigarettes in a group were tested for density and 100 cigarettes in a group for burning cone drop.

2.2.2. Cigarette density detection and data processing. Calibrated the MW3220 density meter. Weigh the cut tobacco of 10 cigarettes which had measured by the density meter with the balance to obtain density coefficient, and completed the instrument calibration.

Density measurement and data processing. The MW3220 density meter can measure the density of the cigarettes on the axial direction, position interval is 1mm. In the training set, 100 cigarettes were randomly selected from the control samples, marked, the density of cigarettes was measured, and the change rate of each position was calculated by software. After density measurement the cigarettes were recovered to detect the burning cone drop, record the position that cone dropped. 20 cigarettes in a group were detected for cigarette density of each sample in the testing set, and the change rate of each position was calculated by software.

![Figure 1. Schematic diagram of detection device for burning cone drop.](image)
2.2.3. Detection of burning cone drop. Use the burning cone drop detection device built by the laboratory (Figure 1). Compressed air drives the cylinder moving to strike cigarette. Compressed air pressure is 0.6 MPa, the striking head is 11 mm away from the cigarette bearing table, the striking position is 30 mm away from the filter end, and the smoking machine adopts ISO standard suction mode, striking was performed 2s after second puff. Since the number of puffs for all samples is less than 6, keep detecting until the burning cone drop or not drop after fifth puff. If the burning cone comes out of the burning line more than 1 mm or drop completely, it will be recorded as burning cone drop, otherwise it will be recorded as not drop. Burning cone drop rate = number of cigarettes occurred burning cone drop /total number of tested cigarettes *100%.

3. Results and discussion

3.1. Establishment of cigarette density segmentation method model

There is an adhesion force due to the twining of the cut tobacco at the cone root to keep the burning cone connected to the cigarette during smoking. And when the cigarette is struck by the burning cone drop device, an inertial force produced by striking make the burning cone separating from the cigarette. Since there is no cigarette paper wrapping, the burning cone may come out from the burning line. Whether the burning cone drop depends on the counterbalance between the adhesion force and the inertial force. If the adhesion force is less than the inertial force, the phenomenon of burning cone drop is tending to occur.

Adhesion force and inertia force are related to cigarettes density. The higher the density of cigarettes in a certain position, reflect the denser of cut tobacco filling there, and the adhesion force is greater. Meanwhile, the higher density will also lead to the higher weight and the greater inertia force of the burning cone when striking. However, according to the actual test results, the burning cone drop rate decreases with the increase of cigarette density. That indicates the increase of adhesion force is greater than inertia force, caused by density increase. This is confirmed by relevant experiments in Section 3.4. Robert W. Jenkins, Jr, et al. reported that the cigarettes density changes greatly near the burning line 4 seconds after smoking, with the value of 306 mg/cm³ at 2 mm after the burning line, 230 mg/cm³ at the burning line, 153 mg/cm³ at 2 mm in front of the burning line and 89 mg/cm³ at 4 mm in the front of the burning cone [12]. This also shows that the increase of cigarette density has no significant effect on the weight of the burning cone. Adhesion force and inertia force are not only related to cigarette density, but also connected with the change rate of packing density in the axial direction of cigarette. Burning cone move along the axial direction during the smoking process, if the cigarettes density drops sharply from high to low, will lead to a rapid decrease in the adhesion force between cut tobacco and a higher tendency for the burning cone drop. Therefore, the burning cone drop is not only related to the cigarette density, but also related its density change rate.

Figure 2. Schematic diagram of division method.
In this research the relationship between super slim cigarette density and its change rate with burning core drop was studied, based on the above analysis. And tried to create a segmentation method model to establish the relationship between the burning cone drop and the filling state of cut tobacco to determine whether the burning cone drop occur. Figure 2 is a schematic diagram of the segmentation method, there is a dotted line \( p = A \times p' + B \) in the rectangular coordinate system of abscissa \( p' \) and ordinate \( p \). The dotted line represents the dividing line of whether the burning cone drop, the points \((p_1', \rho_1)\) in the area below the dotted line satisfy \( A \times p_1' + B > \rho_1 \), while the points \((p_2', \rho_2)\) in the area above the dotted line satisfy \( A \times p_2' + B < \rho_2 \). A and B are model parameters, determined by the training set during modeling; \( \rho_1 \) and \( \rho_1' \) are the density and its change rate at the position where burning cone drop, \( \rho_2 \) and \( \rho_2' \) are the density and its change rate at the position where burning cone not drop.

**Table 2.** Burning line position, cigarette density and its change rate, cone drop condition, judging inequality of the training set.

| Cigarette number | Proceeding puffs | Burning line position (mm) | Density (mg/cm³) | Change rate (%) | Drop or Not | Inequality |
|------------------|------------------|----------------------------|------------------|-----------------|-------------|------------|
| No.1             | 2nd puff         | 15                         | 219              | -4.9            | Not         | -4.9 \( A+B < 219 \) |
|                  | 3rd puff         | 23                         | 212.6            | 1.4             | Not         | 1.4 \( A+B < 12.6 \) |
|                  | 4th puff         | 34                         | 223.2            | 4.7             | Not         | 4.7 \( A+B < 223.2 \) |
|                  | 5th puff         | 42                         | 215.8            | -3.0            | Not         | -3.0 \( A+B < 215.8 \) |
| No.99            | 2nd puff         | 13                         | 252.5            | -17.8           | Drop        | -17.8 \( A+B > 252.5 \) |
| No.100           | 2nd puff         | 14                         | 255.4            | -8.1            | Not         | -8.1 \( A+B < 255.4 \) |
|                  | 3rd puff         | 22                         | 217.4            | 2.3             | Not         | 2.3 \( A+B < 217.4 \) |
|                  | 4th puff         | 32                         | 206              | 1.1             | Not         | 1.1 \( A+B < 206 \) |
|                  | 5th puff         | 42                         | 215.4            | 0.7             | Not         | 0.7 \( A+B < 215.4 \) |

In order to obtain the approximate values of A and B, 100 cigarettes were randomly selected from the control samples as the training set, the burning line position, whether occur burning cone drop, density and density change rate of each cigarettes were obtained by detection and calculation during every puff. Some data of the training set are shown in Table 2. Using the segmentation method model, if burning cone drop occurs, the data of density and its change rate at the position where the burning line is located are substituted into \( p < A \times p' + B \); if burning cone not drop, the data are substituted into \( p > a \times p' + B \), and more than 300 judgment inequalities can be obtained. There are only two results of burning cone drop detection: " drop " and "not drop " so there is no overlap between point \((p', \rho)\) and straight line \( p = A \times p' + B \) in the model. The linear programming software is used to get \( A \in [-4.4186,-4.6132], B \in [186.2255,186.9349] \), take the midpoint of the interval \( A=-4.516, B=186.580 \). According to the position of each burning line of 100 cigarettes in the training set, it can be divided into five sections, which can be obtained by minimizing the total distance between the boundary between two adjacent sections and all burning lines in these two sections, the first section is 0-10 mm, the second section is 11-18 mm, the third section is 19-27 mm, the fourth section is 28-38 mm, and the fifth section is 39-48 mm. It’s unnecessary to take note of the first section because people usually do not flick the ash off when cigarette is just lighted.
3.2. Usage of cigarettes density segmentation method model

Step 1: Take 20 cigarettes as a testing set, it with the same cigarette materials as training set, the filling amount and distribution of cut tobacco can be different. Take a sample testing set with individual cigarette weight of 0.500g ±0.010g as an example, use MW3220 densitometer to measure the actual density of each position of every cigarette in this set, as shown in Figure 3.

![Figure 3. The cigarette density of testing set.](image)

Step 2: Solve the variation rate $\rho'$, as shown in Figure 4.

![Figure 4. The cigarette density change rate of testing set.](image)

Step 3: Substitute $\rho'$ into $\rho=A\times\rho'+B$ to calculate the theoretical density $\rho$, and the result is shown in Figure 5.
Step 4: Compare the actual density and theoretical density of cigarettes at every position, that is, compare the density values at the same position in Figure 3 and Figure 5. When the actual density is less than the theoretical density, it is judged as burning cone drop. The results are shown in Table 3.

Table 3. The judgement result of cone drop.

| Cigarette number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|
| Position         |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |
| 11               | × | × | × |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |
| 12               | × | × | × | × |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |
| 13               | × | × | × | × | × |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |
| 14               | × | × | × | × | × | × |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |
| 15               | × | × | × | × | × | × | × |   |   |    |    |    |    |    |    |    |    |    |    |    |    |
| 16               | × | × | × | × | × | × | × | × |   |    |    |    |    |    |    |    |    |    |    |    |    |
| 17               | × | × | × | × | × | × | × | × | × |    |    |    |    |    |    |    |    |    |    |    |    |
| 18               | × | × | × | × | × | × | × | × | × |    |    |    |    |    |    |    |    |    |    |    |    |
| 19               | × | × | × | × | × | × | × | × | × |    |    |    |    |    |    |    |    |    |    |    |    |
| 20               | × | × | × | × | × | × | × | × | × |    |    |    |    |    |    |    |    |    |    |    |    |
| 21               | × | × | × | × | × | × | × | × | × |    |    |    |    |    |    |    |    |    |    |    |    |
| 22               | × | × | × | × | × | × | × | × | × |    |    |    |    |    |    |    |    |    |    |    |    |
| 23               | × | × | × | × | × | × | × | × | × |    |    |    |    |    |    |    |    |    |    |    |    |
| 24               | × | × | × | × | × | × | × | × | × |    |    |    |    |    |    |    |    |    |    |    |    |
| 25               | × | × | × | × | × | × | × | × | × |    |    |    |    |    |    |    |    |    |    |    |    |
| 26               | × | × | × | × |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |
| 27               | × | × | × |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |
| 28               | × | × | × |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |
| 29               | × | × | × |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |
| 30               | × | × | × |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |
| 31               | × | × | × |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |
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42 × × × × × × × × × × × × × × × × × ×
43 × × × × × × × × × × × × × × × × × ×
44 × × × × × × × × × × × × × × × × × ×
45 × × × × × × × × × × × × × × × × × ×
46 × × × × × × × × × × × × × × × × × ×
47 × × × × × × × × × × × × × × × × × ×
48 × × × × × × × × × × × × × × × × × ×

Note: “×” represent burning cone drop.

The fifth step: according to the sections divided during modeling, the burning cone drop rate is calculated respectively. section burning cone drop rate = number of burning cone drop within a section / (upper section boundary-lower section boundary +1). The maximum value of the burning cone drop rate of each section is the predicted burning cone drop rate of the cigarette. The results are shown in Table 4.

**Table 4. The cone drop rate of each section**

| Drop rate (%) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|
| 2nd section  | 100 | 75 | 88 | 63 | 38 | 0 | 25 | 0 | 38 | 100 | 75 | 0 | 0 | 38 | 0 | 88 | 50 | 25 | 100 | 63 |
| 3rd section  | 100 | 11 | 78 | 78 | 56 | 67 | 67 | 89 | 67 | 89 | 100 | 67 | 33 | 22 | 100 | 100 | 100 | 89 | 100 | 100 |
| 4th section  | 100 | 73 | 100 | 91 | 82 | 36 | 82 | 91 | 55 | 91 | 45 | 73 | 73 | 9 | 27 | 82 | 100 | 73 | 91 | 18 |
| 5th section  | 20 | 50 | 80 | 0 | 0 | 0 | 10 | 40 | 0 | 0 | 100 | 60 | 0 | 60 | 30 | 0 | 10 | 20 | 40 | 0 |
| predicted value | 100 | 75 | 100 | 91 | 82 | 67 | 82 | 91 | 67 | 100 | 73 | 73 | 60 | 100 | 100 | 100 | 89 | 100 | 100 |

The average burning cone drop rate of 20 cigarettes in the testing set is:

\[(100\%+75\%+100\%+91\%+82\%+67\%+82\%+91\%+100\%+100\%+73\%+73\%+60\%+100\%+100\%+100\%+89\%+100\%)/20=87.4\%\]

The actual drop situation is detected by the burning cone drop detection device, and the result of the testing set sample is 82%.

3.3. **Accuracy verify of cigarette density segmentation method model**

3.3.1. **Trueness of the model.** Twelve representative testing sets were selected to verify the trueness of the model, including five samples with different individual cigarette weight (0.500g, 0.530g, 0.560g, 0.590g, 0.620g), and seven samples with different distribution of cut tobacco (0#, 1#, 2#, 3#, 4#, 5#, 6#). Figure 6 compares the predicted and measured values of the burning cone drop rate. It can be seen from the figure
that the predicted and measured values of the burning cone drop rate of each sample are basically consistent, and the data points fall near the 1:1 line. R² is 0.98, D index is 0.99, all close to 1, and nRMSE is 11.8%.

**Figure 6.** Comparison between predicted and observed drop ratio of cut tobacco distribution samples.

**3.3.2. Precision of the model.** One cigarette was randomly selected from the control samples, and it was continuously detected for 10 times by densitometer. The nondestructive testing method of cigarette density makes it possible to test the same sample for many times, so that the repeatability of the method used in the model can be directly investigated. Figure 7 shows the density of each position of the same cigarette measured 10 times continuously. From Figure 7, we find that there are some small fluctuations in the repeatability of each position, that comes from the random error of density data measured by densitometer. After solving the model, the predicted burning cone drop rate of 10 repeated tests (Table 5) is finally obtained, and the coefficient of variation is 6.5%.

**Figure 7.** The cigarette density of 10 measurements from a cigarette.
### Table 5. The cone drop judgement of 10 measurement result from the same cigarette.

| Consecutive replications | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|--------------------------|---|---|---|---|---|---|---|---|---|----|
| Position                 | 11| 12| 13| 14| 15| 16| 17| 18| 19| 20 |
|                          |   |   |   | x | x | x | x | x | x |    |
|                          | 21|   |   |   |   |   |   | x | x |    |
|                          | 22| x | x | x | x | x | x | x | x | x  |
|                          | 23| x | x | x | x | x | x | x | x |    |
|                          | 24| x | x | x | x | x | x | x | x |    |
|                          | 25| x | x | x | x | x | x | x | x |    |
|                          | 26| x | x | x | x | x | x | x | x | x  |
|                          | 27| x | x | x | x | x | x | x | x | x  |
|                          | 28|   |   |   |   |   |   | x |   |    |
|                          | 29|   |   |   |   |   |   |   |   |    |
|                          | 30|   |   |   |   |   |   |   |   |    |
|                          | 31| x | x | x | x |   | x | x | x |    |
|                          | 32| x | x | x | x | x | x | x | x |    |
|                          | 33| x | x | x | x | x | x | x | x |    |
|                          | 34| x | x | x | x | x | x | x | x |    |
|                          | 35| x | x | x | x | x | x | x | x | x  |
|                          | 36|   |   |   |   |   |   |   |   |    |
|                          | 37|   |   |   |   |   |   |   |   |    |
|                          | 38|   |   |   |   |   |   |   |   |    |
|                          | 39|   |   |   |   |   |   |   |   |    |
|                          | 40|   |   |   |   |   |   |   |   |    |
|                          | 41|   |   |   |   |   |   |   |   |    |
|                          | 42|   |   |   |   |   |   |   |   |    |
|                          | 43|   |   |   |   |   |   |   |   |    |
|                          | 44|   |   |   |   |   |   |   |   |    |
|                          | 45|   |   |   |   |   |   |   |   |    |
|                          | 46|   |   |   |   |   |   |   |   |    |
|                          | 47|   |   |   |   |   |   |   |   |    |
|                          | 48|   |   |   |   |   |   |   |   |    |

| Predicted drop rate | 67% | 67% | 67% | 67% | 67% | 67% | 78% | 67% | 78% | 67% |

Note: “x” represent burning cone drop.
3.4. Application of cigarette density segmentation method model

3.4.1. Samples with different tobacco packing density. Samples with different tobacco packing density can be obtained by changing the individual cigarette weight during rolling. Figure 8 shows the cigarette density of the samples, that increase with the increase of individual cigarette weight.

![Figure 8. Cut tobacco densities of cigarette weight samples.](image)

Figure 8. Cut tobacco densities of cigarette weight samples.

Figure 9 is the average value of the burning cone drop rate of samples with different individual cigarette weight. The burning cone drop rate decrease steadily with the increase of individual cigarette weight. This result confirms the statement in Section 3.1, As the individual cigarette weight increases, its density and filling amount of cut tobacco are increase, that can provide greater adhesion force and inertial force, and the adhesion force is increased greater than the inertial force. It can also be seen from figure 9 that the predicted burning cone drop rate is very close to the measured rate. Through calculation, the $R^2$ of fitting line between the predicted rate and the measured rate is 0.99.

![Figure 9. Average drop ratio of cigarette weight sample.](image)

Figure 9. Average drop ratio of cigarette weight sample.

3.4.2. Samples with different distribution of cut tobacco. The average density of 0-52 mm in Table 6 indicates the density of the whole cigarette. Because the position after 52 mm is too close to tipping paper, the density measurement error is very large. 11-48 mm is the range from the second to the fifth section of
the tested sample. The average density of 0-52 mm of each sample in the table is similar, which indicates the total filling amount and individual cigarette weight are similar.

The average density of the 11-48 mm range of 2# is obviously higher than others, because the ecetreur discs don’t have pocket, the cigarette does not have dense-end, and the filling amount of cut tobacco in the middle is sufficient. The most uniform distribution of cut tobacco in 2# sample is also reflected in the smallest coefficient of variation (4.8%) in this range.

Table 6. Average density, coefficient of variation, prediction of drop rate, observed drop ratio of cut tobacco distribution sample.

| Sample | 0-52 mm | 11-48 mm | Predicted drop rate (%) | Measured drop rate (%) |
|--------|---------|----------|-------------------------|------------------------|
|        | Average density (mg·mm⁻³) | Coefficient of variation (%) | Average density (mg·mm⁻³) | Coefficient of variation (%) |
| 0#     | 223.4   | 14.6     | 213.8                   | 9.4                    | 45.2                  | 45                  |
| 1#     | 219.3   | 11.7     | 213.3                   | 6.3                    | 34.4                  | 34                  |
| 2#     | 227.5   | 11.3     | 232.7                   | 4.8                    | 2.7                   | 0                   |
| 3#     | 223.5   | 12.1     | 216.6                   | 6.5                    | 24.0                  | 20                  |
| 4#     | 220.0   | 11.4     | 215.2                   | 6.6                    | 27.0                  | 32                  |
| 5#     | 223.9   | 11.3     | 221.2                   | 6.5                    | 21.0                  | 20                  |
| 6#     | 221.8   | 10.5     | 219.1                   | 5.8                    | 21.7                  | 28                  |

In figure 10, the density of all samples except 2# dropped sharply in the second section, that was caused by the filling amount of cut tobacco changed in the transition from the deep pocket area to the flat area on the ecetreur discs. Among them, the density of 0# sample has the steepest decreasing trend and the largest value, that is mainly due to the deepest (2.5 mm) and widest (24 mm) pocket of 0# ecetreur discs. This makes the maximum amount of cut tobacco filled in the tight head area, and the minimum amount of cut tobacco filled in the middle part, it is also reflected from the lowest density of 0# in the third and fourth sections. Moreover, the density of 0# is all decreased in third section, the previous analysis has shown that the area with a low density and a negative change rate will have a higher drop tendency, so burning cone drop rate of this section is higher than other whether predicted or detected.

The pocket depth of 1#’s ecetreur discs is same as 0#’s, just the pocket width is 16 mm, that the tobacco in the middle of cigarettes is sparse too, so the density of the corresponding position in the middle is the second lowest. 3#’s and 4#’s ecetreur discs have lower pocket depth at the back than 1#’s, that can hold less tobacco, so their graph line position in the middle is higher than 1#. 5#’s ecetreur discs has a lower pocket depth, so the density in the middle of cigarettes is higher. The small pocket of 6#’s ecetreur discs increases the filling amount of cut tobacco in the middle of cigarettes, so a platform with increased density appears in the fourth section in Figure 10. 2# uses a flat ecetreur disc, the density distribution of the whole cigarettes is the most uniform from front to end, there is no sharp drop of density and no very low-density position, so the burning cone drop rate should be very low, that is consistent with the results in Table 6.
Figure 10. Average density in different position within 2nd to 5th section of cut tobacco distribution samples.

4. Conclusion
When the adhesion force of cut tobacco at the root of the burning cone is less than inertial force, it will appear as the burning cone drop, and vice versa. Adhesion force and inertia force are related to cigarette density and its change rate. With the increase of cigarette density, the adhesion force and inertia force will increase, the increase of adhesion force is higher than the inertial force’s because of burning consumption. When the density change rate is negative, the burning cone side density is high, the inertia force is big, and the tobacco side density is low, the adhesion force is small, so the burning cone is easy to drop, and vice versa.

The effect of density and its change rate on burning cone drop is considered in the segmentation method model. The model coefficient range obtained by using 100 super slim cigarettes of a certain brand as training set is $A \in [-4.4186, -4.6132]$, $B \in [186.2255, 186.9349]$. If the cigarette materials and tobacco blend are changed, A and B will also change. Verifying the trueness of the model, it is found that the predicted and the measured value basically fall near the 1:1 line, $R^2$ and D index are 0.98 and 0.99 respectively, nRMSE is 11.8%. The precision of the model is that the coefficient of variation of the predicted burning cone drop rate is 6.5% after 10 consecutive repeated tests.

The model was applied to samples with different density and distribution of cut tobacco, the fitting lines $R^2$ of predicted and measured burning cone drop rate were 0.99 and 0.93, respectively. The predicted and measured values of the burning cone drop rate decreased with the increase of individual cigarette weight. The burning cone drop rate of samples with different distribution of cut tobacco is $0\# > 1\# > 4\# > 6\# > 3\# > 5\# > 2\#$.

The segmentation method model can predict the burning cone drop rate of cigarettes with different individual cigarette weight and different distribution of cut tobacco. Even if the cigarette materials and tobacco blend are changed, it can be predicted by re-modeling with a new training set, which has
strong self-adaptive ability. For cigarettes that only change the filling amount or distribution of cut tobacco, it is unnecessary to ignite the samples, just measure the cigarettes density data the rate of burning cone drop can be predicted, thus achieving the nondestructive detection. Only the first position that the drop occurs can obtained by burning cone drop detection device, while the segmentation method model can get all the possible drop positions of the whole cigarettes with an accuracy of 1mm, that is beneficial to take targeted measures to improve the distribution of cut tobacco and reduce the burning cone drop rate. This research fills the blank of the internal relationship between the filling state of cut tobacco and the burning cone drop.

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