NUMERICAL SIMULATION OF FACTORS AFFECTING THE WEIGHT DISTRIBUTION UNIFORMITY OF VIBRATING TROUGH MATERIALS

Pingfang ZHOU[1,*], Fei QI[1], Yu HU[1], Liang CHEN[1], Yuhua CHEN[1]

To address the quality fluctuations of tobacco stems after the stalk pressing process caused by uneven supply of vibration trough, using EDEM software for the simulation of the conveying process of tobacco stem particles on vibrating troughs, this research studied the trajectory and distribution law of different types of tobacco stem particles on vibrating troughs and analyzed the effects of amplitude, vibration frequency, and vibration direction angle on tobacco stem weight distribution in conveying process. The relationship curve between vibration parameters and weight distribution uniformity was drawn. Simulation results revealed that in the vibrating trough conveying process along vertical direction, material presented a gradient grading distribution. Short tobacco stems are mostly distributed in particle group bottom layer and long tobacco stems and stalks are distributed in particle group upper layer. The improvement effect of material weight distribution uniformity on vibrating trough conveying process was enhanced with the increase of vibrating trough frequency. Also, increase of amplitude and vibration direction angle first increased and then decreased the improvement effect of material weight distribution uniformity. Vibration frequency of 7.5 Hz, amplitude of 16 mm, and vibration direction angle of 20° were found to be the preferred parameter combination. This study provided theoretical guidance for research on vibrating trough devices.

Keywords: Vibrating trough; Tobacco stems; Discrete Element Method; Conveying uniformity; Motion orbit

1. Introduction

In cigarette processing, the function of stem press is to change the shape of tobacco stems and flatten them to the desired thickness to provide favorable process conditions for subsequent cutting processes to obtain high cutting quality[1]. When multiple stem pressing machines work in parallel, different feeding amounts cause inconsistent stem pressing thicknesses, resulting in variations in silk making quality. Tobacco stem raw materials are transported using vibrating troughs and are evenly distributed among multiple machines by evenly arranging partitions and blanking ports. However, tobacco stems are unstable, have poor continuity and become unevenly distributed during conveying process through vibrating trough,

[1] Wuhan Cigarette Factory, China Tobacco Hubei Industrial Co., Ltd., Wuhan, CHINA
*Corresponding author's email: e-mail: 1348191682@qq.com

resulting in unbalanced feeding to stem pressing machine. Currently, uniformity issues in tobacco industry, such as tobacco feeding uniformity, formula threshing and feeding uniformities, re-bake leaf quality uniformity, and conveyed material supply uniformity, have become a hot research topic. This research aimed to ensure balanced distribution quality through uniform feeding. Regarding specific engineering problems, material movement analysis methods under vibration conditions are applied to investigate the movement rules of tobacco stem vibration grooves and obtain balanced feeding.

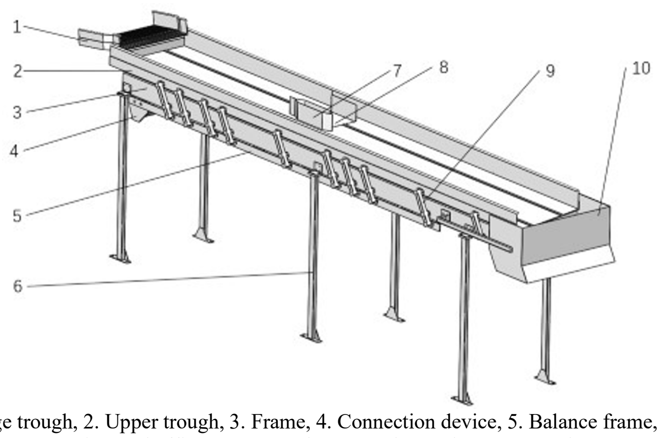
Bulk material transportation and storage are often related to the particle size of the material to be transported and vibrating trough parameters [2.3.4]. Vibratory conveying technology has been applied in several areas. Vibrating troughs were categorized into link, electromagnetic and inertial types according to vibration source. Several research works have been performed on electromagnetic and inertial vibrating trough types. For example, Wang et al. [5] investigated the effects of amplitude, frequency, and vibration direction angle on material mass flow rate. Material mass flow rate was found to be linearly related to amplitude and frequency and non-linearly related to vibration direction angle. Liu et al. [6] decreased cut tobacco moisture content during transportation process by optimizing and adjusting parameters such as exciter frequency and eccentricity coincidence degree. Su et al. [7] applied EDEM software to analyze the impacts of vibration direction angle and particle size on the deviation of material quality falling into the next equipment during vibrating feeding process. Kong et al. [8] investigated the impacts of the interaction of material and equipment in jumping and jumping-sliding zones under vibration conditions. Boriskina et al. [9] developed a particle motion model for vibrating troughs to determine appropriate parameters related to particle motion on vibrating trough. Gelnar et al. [10] performed experimental tests on material particles with different lengths and found that changing particle shape can decrease friction and resistance during transportation. This research [11] studied the effect of drive motor mounting position on material particles. It [12] also focused on the effects of vibrating trough parameters on conveying capacity. Investigation of granular material transversal dispersion on vibrating troughs revealed that particle dispersion was increased with the increase of mean particle diameter [13]. In addition, these articles [14-15] analyze the effect of parameters by developing mathematical models.

Particle motion state on connecting rod type vibrating trough was found to be basically similar to those of electromagnetic and inertial types. However, few research works are available on particle distribution uniformity on vibrating trough surface. This research first measured tobacco stem material size and flow rate on vibrating trough production line. Then, it analyzed the distribution of each tobacco stem material along different directions at diverter partition based on tobacco stem material movement trajectory on vibrating trough as well as throwing index theory.

Finally, using EDEM software, the transportation process of tobacco stem materials on vibration trough under different working conditions was numerically simulated, vibration trough parameters were optimized, and weight distribution uniformity of tobacco stem materials on vibration trough was improved. This study provided a reference for vibrating trough design in terms of the optimization of the dynamic parameters of the equipment itself.

2.Working principle and problem analysis of vibration trough

As illustrated in Fig.1, vibration troughs are mainly composed of upper trough body, rocker, frame, legs, balance frame and other parts. The motor continuously rotates the eccentric shaft through triangle belt, driving connecting rod end to reciprocate. The connecting rod makes the upper trough body and balance frame move along the direction specified by the rocker through connecting device. The trough body vibrates along the tilt direction of rocker, causing tobacco stem material in trough to keep moving forward. It was seen from Fig. 1 that when tobacco stem material was transported to the middle section of the trough, material flow was divided into two parts by diverter partition. One part of the material falls into the first stem pressing machine at the middle outlet, and the other part falls into the second stem pressing machine at vibrating trough end. During vibrating trough working process, due to continuous vibration on the vibrating trough, it is difficult to ensure that the flow rate of the material falling into the two stem pressing machine is uniform. Long-term uneven discharging causes the accumulation of tobacco stem materials in the follow-up process. Huge differences were observed in the thickness and moisture content of tobacco stems after they were pressed by the two stem pressing machines. Then, uneven material distribution affected the quality of tobacco stems in subsequent shredding process and ultimately resulted in fluctuations in the quality of the produced stems.



1. Discharge trough, 2. Upper trough, 3. Frame, 4. Connection device, 5. Balance frame, 6. Legs, 7. Diverter baffle, 8. Front outlet, 9. Rocker and 10. Rear outlet

Fig.1 Structure of vibrating trough

3 Model establishment and experimental design

3.1 Model establishment and simulation parameter setting

Discrete element method (DEM) is a numerical approach applied to model granular flow at particle level and is suitable for industries that handle different granular materials [16.17]. Tobacco stem material usually contains tobacco stem particle materials with different lengths and a small amount of tobacco particle materials. To verify the stability of the length and shape of tobacco stems, tobacco stem materials were collected from the production line for statistical experiments. The average thickness of tobacco stems without tobacco stalks was about 4mm thickness variation range of 3~6mm. Also, the average thickness of tobacco stalks was about 10mm with thickness variation range of 9~12mm. The lengths of tobacco stalks were mainly distributed in two intervals of 0~20mm and 20~30mm. The specific statistical results of the variation ranges of tobacco stem and tobacco stalk length are summarized in Table 1:

Table 1

Material Size Distribution of Tobacco Stalks

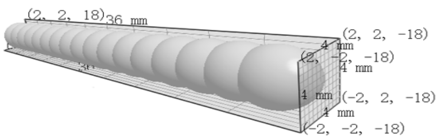
Number	1	2	3	4	5	6	7	8
Length(cm)	0~2	2~3	3~4	4~5	5~6	>6	0~2	2~3
Proportion(%)	17.7	28.7	25.5	11.2	3.5	3	5.1	5.3

In Table 1, numbers 1 through 6 are tobacco stems of corresponding lengths, number 7 denotes short stalks, and number 8 presents long stalks. Tobacco stems and stalks with different lengths could be modeled according to their corresponding proportions after being rounded based on the above distribution rules. Tobacco stem and stalk models are illustrated in Fig. 2. Simulation parameters were set as follows: The inner walls of vibration trough and diverter baffle were both made of 304 stainless steel. The gravity coefficient of vibration trough and tobacco stem material was 9.81N/kg. Contact model type was selected to be Hertz-Mindlin non-sliding contact model [18]. According to relevant research works [19] and actual experience, material property parameters and friction coefficient of tobacco stem material and vibration trough were set based on the values presented in Table 2. The discharge port was considered as tobacco stem material production source and discharge flow rate was consistent with actual flow rate and was set to 0.833kg/s. Total calculation time was set to 30s, simulation step size was set to 30% (9.245e-6s), sampling time was 0.05s, and grid size was 3R(R means the size of the smallest particle of the particles that make up the stem material.). After setting the simulation conditions, the 3D movement trajectory of a certain tobacco stem material was exported, as illustrated in Fig. 3. Material movement trajectory was basically consistent with actual movement situation and parameter settings were reasonable.

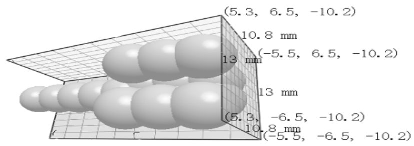
Table 2

Parameter values of tests

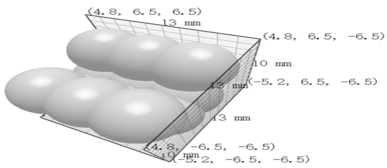
Parameter	Numerical size	
	Tobacco stem material	304 stainless steel
Poisson ratio	0.25	0.285
Density (kg·m $^{-3}$)	830.6	7930
Shear modulus (Gpa)	4.1e+07	7.94e+10
Collision recovery coefficient	0.4	0.5
Static friction coefficient	0.3	0.5
Rolling friction coefficient	0.01	0.01



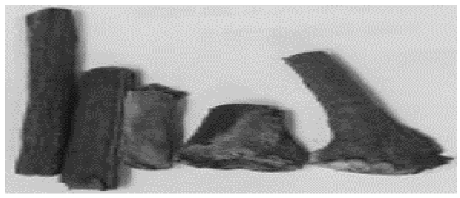
(a)-Tobacco stem model



(b) –Short tobacco stalk model



(c) - Long tobacco stalk model



(d) - Physical picture of tobacco stem material

Fig. 2 Simplified modeling of tobacco stems and stalks

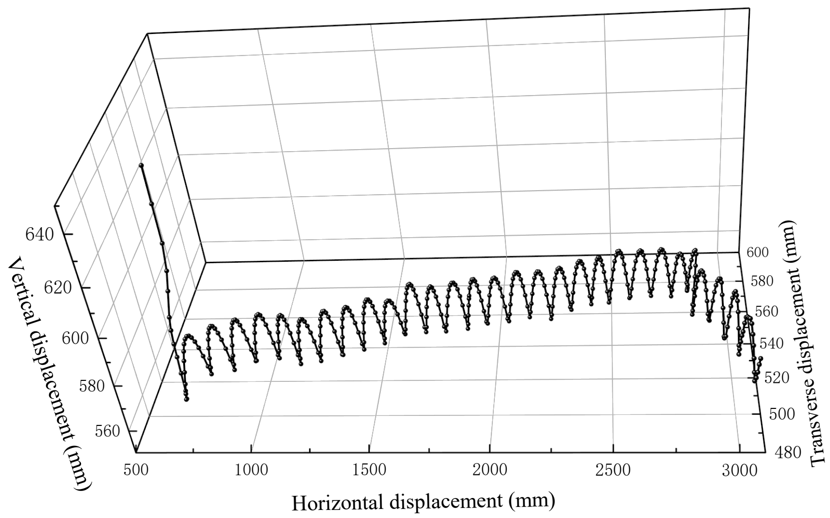


Fig. 3 3D trajectory of a tobacco stem on a vibrating trough

3.2 Vibration trough parameter setting

Throw coefficient [5] (K) is an important parameter for measuring material movement in vibration plane. This coefficient could be expressed as the ratio of maximum vertical trough acceleration to gravity acceleration [20]. When K was greater than 1, tobacco stem material left the trough and jumped along a parabolic trajectory [21]. When the material shape approached the spherical surface, the main motion component was rolling and when material shape tended to ellipsoid, the object mainly slid along vibration surface [22]. When K was too large and trough rigidity and strength were insufficient, normal conveying work was changed and premature trough failure occurred. K was calculated using Eq. (1) as:

$$K = \frac{4\lambda\pi^2 f^2 \sin\theta}{g\cos\alpha} \tag{1}$$

where λ is vibrating trough amplitude (mm), f is vibrating trough frequency (Hz); θ is vibration direction angle of vibrating trough (degrees), g is universal gravitational constant (m/s^2), and α is vibrating trough inclination angle (degrees).

From Eq. (1), it was seen that the main influencing factors on tobacco stem movement state were amplitude, vibration frequency, vibration direction angle and inclination angle of vibration trough. By adjusting characteristic parameters, weight distribution uniformity during tobacco stem transportation could be improved. In order to systematically investigate the influences of the above three characteristic parameters on tobacco stem weight distribution uniformity, these parameters were applied as experimental factors. The specific change values of each factor are presented in Table 3.

Table 3

Vibrating Trough Parameters Parameters	Ranges
Amplitude $\lambda(mm)$	12/16/20/22/25
Frequency $f(Hz)$	5/5.5/6.5/7/7.5
Vibration direction angle θ(°)	15/20/25/30/35/40

3.3 Weight distribution uniformity assessment

During material transportation process, the effect of vibrating trough on material presented a certain correlation with material layer position where the material was located. Particles closer to the bottom were more affected by trough body vibration and the movement trajectories of particles closer to the upper part tended to be smoother. Tobacco stem material movement trajectory on vibrating trough was extracted and an appropriate statistical area was selected as shown in Fig. 4. The effects of vibrating trough on the kinematic properties of different types of tobacco stem materials were explored by measuring stem material distribution in specified areas under different vibration conditions.

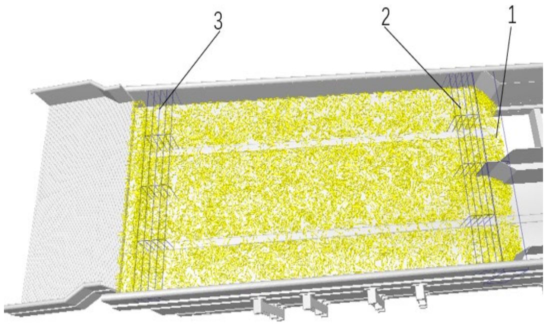
Coefficient of variation (CV) is often applied to describe data dispersion and is an effective way for the evaluation of material weight distribution uniformity. Smaller values of CV meant more uniform material distribution [23]. This indicated that better effects of stability and uniformity could be achieved [24]. Two weight sensors along vibrating trough conveying direction were set up, both with dimensions of 160×200×1000mm. The spaces occupied by the weight sensors at vibrating trough front and diverter baffle front were recorded as front-end space and back-end space, respectively, as illustrated in Fig. 4. EDEM post-processing was used to measure tobacco stem weight in each square and the mean x_i and standard deviation s of tobacco stem weight were calculated in the group of squares $\bar{x}$ and the variations of the front and rear spaces at different times were obtained using Eqs. (2~5). The average CV_1 and CV_2 values of tobacco stem distribution weight at the front and rear ends of the vibrating trough within a certain period of time was calculated after tobacco stem material flow rate in vibrating trough was stabilized. Difference of CV (ΔCV) at front and rear ends were applied as an index of the uniformity effect of tobacco stem weight distribution.

$$\bar{x} = \frac{1}{m}\sum_{i=1}^{m} x_i \tag{2}$$

$$s = \sqrt{\frac{1}{m-1}\sum_{i=1}^{m}\left(x_i - \bar{x}\right)^2} \tag{3}$$

$$CV = 100 \times \frac{s}{\bar{x}} \tag{4}$$

$$\Delta CV = CV_1 - CV_2 \tag{5}$$



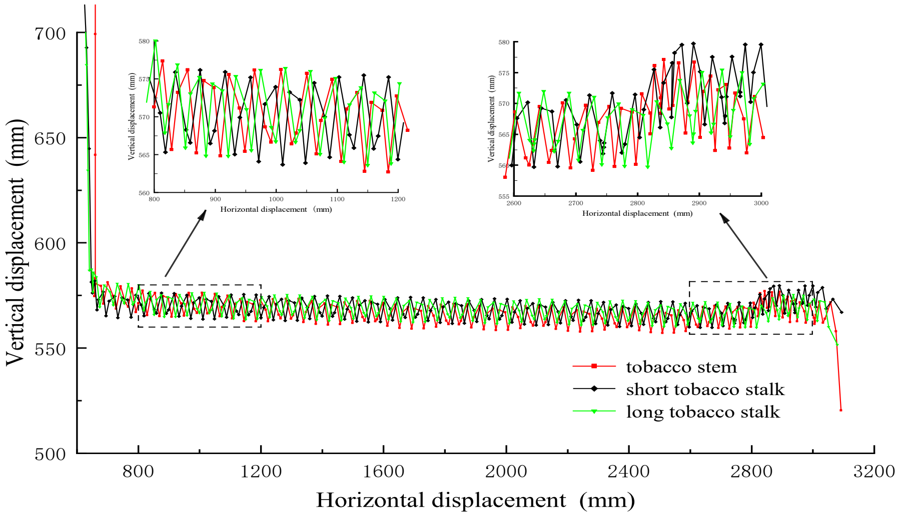
1. Material distribution statistics area, 2. Back-end area, and 3. Front-end area

Fig. 4 The movement of tobacco stem material on vibrating trough

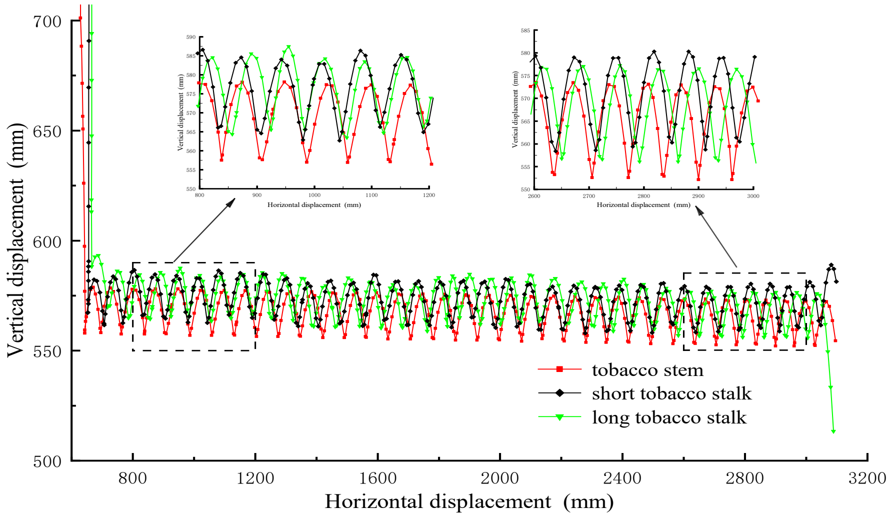
4 Analysis

4.1 Material movement trajectory analysis

After tobacco stem material flow rate on vibration trough was stabilized, movement trajectories of different types of tobacco stem material particles on vibration trough before entering vibration trough diversion baffle were extracted, as illustrated in Fig. 5. When statistical material flow rate was stable, the average position of each type of tobacco stem material along vertical and horizontal directions in the specified statistical area under different parameter conditions are presented in Fig. 6. The numbers 1 to 8 in the figure correspond to different tobacco stem materials presented in Table 1.

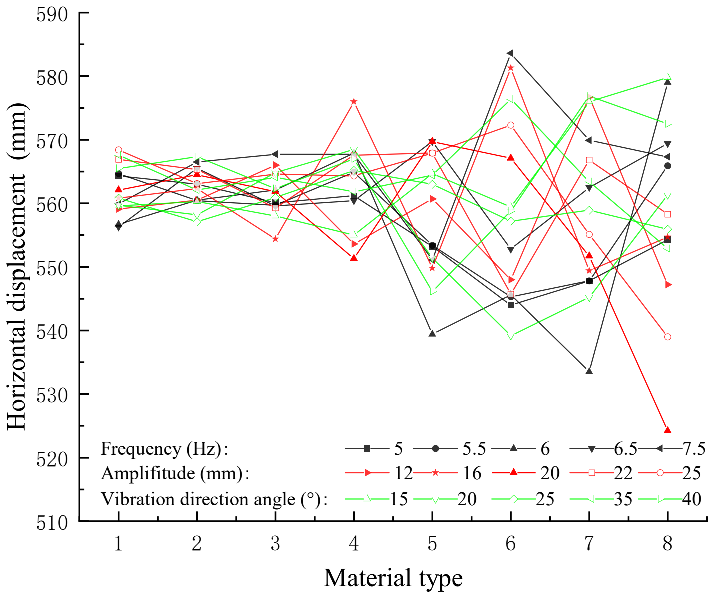


(a) 5Hz-20mm-30°

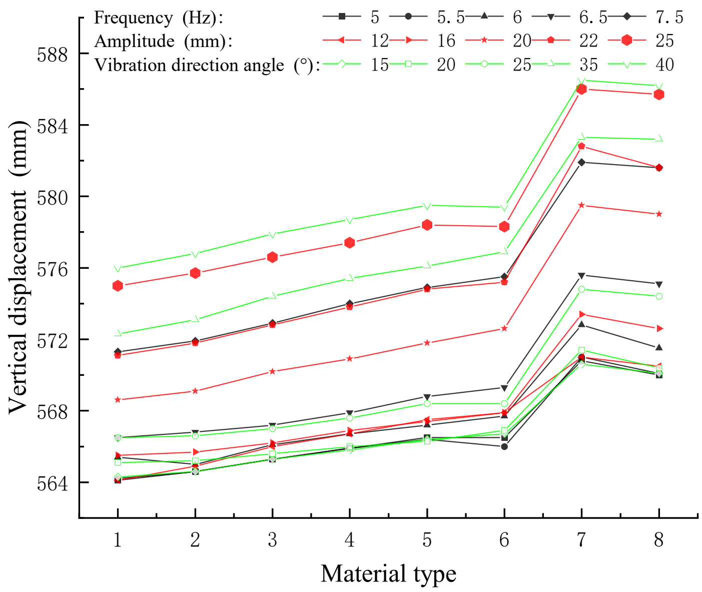


(b) 6Hz-20mm-30°

Fig. 5 The trajectory diagrams of different particles



(a) Horizontal displacement distribution diagrams of tobacco stem materials



(b)Vertical displacement distribution diagrams of tobacco stem materials

Fig. 6. Distribution of tobacco stems under different working conditions

It was seen from Fig. 5 that, for small K and slow material flow rates, tobacco stems were prone to back mixing at outlet due to the presence of diverting baffle. During transportation, tobacco stalks and long stems climb upwards, while short tobacco stems tend to stay at the bottom after falling into vibration trough. Along horizontal direction, tobacco stem materials had no obvious distribution pattern and tended to be randomly distributed. Viewed along vertical direction, with the increase vibration trough frequency, amplitude, and vibration direction angle, vertical displacements of different types of tobacco stems and stalks were increased. In the material conveying process, irregularly shaped tobacco stalks and longer tobacco stems were mainly distributed in the upper layer of particle group. Short tobacco stems with regular shapes, shorter lengths and lighter weights were mainly distributed in particle group bottom layer. Tobacco stems were loosened and homogenized in the vertical plane by vibratory trough, showing a step distribution related to the length. Short stalks were distributed in the upper layer of the material relative to long stalks. Increase of dimensional deviation between material particles intensified the effect on the weight deviation of the falling material at the two outlets[5]. During the transportation process, particle size had a certain effect on material distribution uniformity. As the size distribution of material particles was widened, materials were less likely to be classified.

4.2 Vibration frequency simulation test and result analysis

Amplitude and vibration direction angle were set to 20mm and 30°, respectively, and vibration frequency range was similar to those presented in Table 3. After 15 seconds, the tobacco stem material flow rate under different frequencies remained stable. At faster tobacco stem material flow rates, the weight of tobacco stem material left on the vibrating trough was less at stable flow rates. When statistical flow rate was stabilized, material flow rate was expressed as the mass of remaining tobacco stems on vibrating trough. This mass was represented by M (kg). The results are presented in Fig. 7 and Table 4.

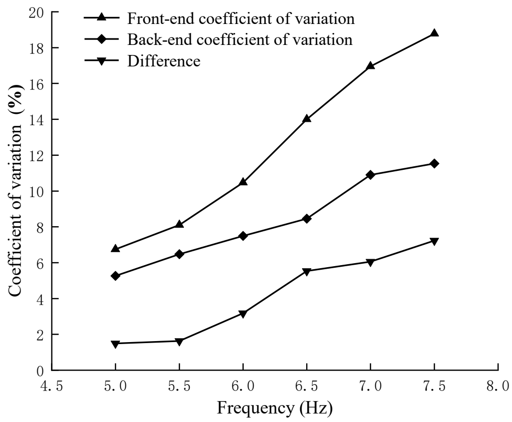


Fig. 7 Effects of different frequencies on the uniformity of weight distribution

Table 4

Test results at different frequencies

Frequency (Hz)	M (kg)	K
5	7.96	1.006
5.5	6.32	1.217
6	6.31	1.448
6.5	4.52	1.700
7	3.76	1.971
7.5	3.29	2.263

From Fig. 7 and Table 4, it was seen that with the increase of vibration frequency, CV of front-end and back-end of vibrating trough was increased with the increase of frequency. With the increase of vibration frequency, the ability of vibrating trough to improve the weight distribution uniformity of tobacco stems in conveying process was gradually increased. The reason for this situation was that at small vibrating trough frequencies, the distance the tobacco stems move during each vibration process was shorter and tobacco stems continued to accumulate on vibrating trough during transportation. Due to structure obstruction, the frequency of material exchange with the area next to it was low and only a small amount of tobacco stem material in the upper layer was exchanged with other areas. Therefore, when tobacco stems were evenly fed, the CV value of the back-end was small. With the increase of frequency, the flow rate of tobacco stem material was increased, the stack thickness of tobacco stem material was decreased, and contact probability between the upper material and vibrating surface was increased. The upper material movement trajectory was more strongly affected by trough body and the front and rear uniformities of the material were improved. The effect of outlet material uniformity distribution was significantly improved.

4.3 Amplitude simulation and result analyses

Vibration frequency and vibration direction angle were set to 7Hz and 30°, respectively, and amplitude variation range was similar to that illustrated in Table 3. The changing patterns of the CV of tobacco stem weight distribution in the two spaces at the front and back ends of the vibration trough are presented in Fig. 8. Weight statistical results and coefficient values that represent the flow rate are presented in Table 5.

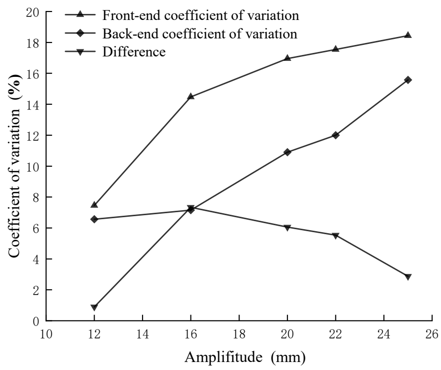


Fig. 8 Effects of different amplitudes on the uniformity of weight distribution

Table 5

Test Results at Different Amplitudes

Amplitude (mm)	M (kg)	K
12	8.25	1.183
16	5.41	1.577
20	3.76	1.971
22	3.26	2.169
25	2.81	2.465

From Fig. 8 and Table 5, it was seen that with the increase of amplitude, the CV of the front-end and back-end of vibrating trough were increased with the increase of amplitude. The ability of vibrating trough to improve tobacco stem weight distribution uniformity was first increased and then decreased. The reason for this situation was that at low vibration trough amplitudes, tobacco stem material was thrown at low heights during transportation process. Under these situations, flow rate was slow, and material accumulated seriously; therefore, the improving efficiency of tobacco stem weight uniform distribution was low. When amplitude was increased to a certain size, tobacco stem movement on the vibration trough perpendicular to the direction of vibration trough became more intense and the increase of amplitude increased the flow rate of tobacco stem material at the same time. When tobacco stem particles were thrown in the air, the collision movement between the particles became more intense. As collision was intensified, the lateral displacement of tobacco stem material was increased, and the uniform distribution effect of tobacco stem material was gradually decreased.

4.4 Vibration direction angle simulation test and result analyses

Amplitude and vibration frequency were set to 20mm and 7Hz, respectively, and vibration direction angle change range was similar to that shown in Table 3. The change pattern of the CV of tobacco stem weight distribution at the front and rear ends of vibrating trough are illustrated in Fig. 9. Weight statistical results and K representing the flow rate are presented in Table 6.

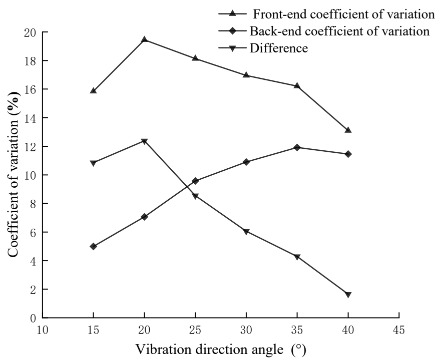


Fig. 9 Effects of different vibration direction angles on weight distribution uniformity

Table 6

Test Results under Different Vibration Direction Angles

Vibration direction angle (°)	M (kg)	K
15	7.78	1.021
20	5.43	1.349
25	4.30	1.667
30	3.76	1.971
35	3.65	2.262
40	3.79	2.534

From Fig. 9 and Table 6, it was seen that with the increase of vibration direction angle, the CV of the front-end of tobacco stem material was first increased and then gradually decreased, while that of the back-end was gradually increased. The ability of vibrating trough to improve distribution uniformity was also first increased and then gradually decreased. When vibration direction angle was small, tobacco stem material flow rate was slow, the force parallel to trough body surface was increased, and the force perpendicular to trough body surface was small. Tobacco stems were piled up to a certain height at diverter baffle. With the increase of vibration direction angle, material flow rate was increased. The effect of vibration trough on improving tobacco stem material uniform distribution was gradually increased. When vibration direction angle was greater than a certain value, tobacco stem flow rate on vibration trough was not increased, but decreased. This was because larger vibration direction angles resulted in greater force perpendicular to vibrating trough moving surface exerted on tobacco stem each time it moved. When the angle between force and conveying direction was increased to a certain extent, tobacco stem stayed in the air for too long. This decreased the number of contacts between tobacco stems and vibrating trough. This had a certain hindering effect on material transportation and reduced the effect of vibration trough on improving tobacco stem uniform weight distribution during transportation process.

5 Conclusions

Through the simulation test analysis of material movement under different vibration parameters during vibration trough conveying process, that the following conclusions were drawn:

(1) The movement trajectory of material particles on the vibration trough was analyzed. Tobacco stem particles showed gradient distribution characteristics. Lower weights and shorter tobacco stems resulted in more likelihood of their distribution at the bottom of material particle group. Tobacco stalk materials with irregular shapes and long tobacco stem materials were mostly distributed in the upper layer of material particle group.

(2) In order to determine the effects of mechanical and physical characteristics on tobacco stem material weight distribution, the possibility of uniform discharge from trough cold be realized by changing the amplitude and frequency of vibrating trough as well as vibration direction angle. EDEM simulation revealed strong relationships among vibrating trough parameters, material looseness and uniformity effect during vibrating trough conveying process. Increase of vibration frequency greatly improved material weight distribution uniformity during vibrating trough conveying process. The improvement effects of amplitude and vibration direction angle on material weight distribution uniformity was first increased and then decreased. When vibration trough parameter combination frequency was 7.5Hz, the amplitude was 16mm and vibration direction angle was 20°, the improvement effect of vibration trough on material weight distribution uniformity is the best and can better achieve balanced feeding.

Numerical simulations were performed on vibration trough conveying process under different working conditions and further understanding of material transportation rules on vibrating trough was obtained, which provided a certain reference for the subsequent design of vibrating trough.

REFERENCES

[1]. *Y. M. Liu, S. Q. Zhang.* The role of improved cleaning devices for segement presses in equipment processing. Public Communication of Science & Technology, **vol. 5**(15): 2013, pp. 69, 71.(in Chinese)

[2]. *X. F. Luo, L. Zhao, M. H. Zhang, et al.* DEM study on the effects of pellet characteristics on particle flow in rectangular hopper, Powder Technology, **vol. 373**, 2020, pp. 476-487.

[3]. *J. P. Qiao, C. L. Duan, K. J. Dong, et al.* DEM study of segregation degree and velocity of binary granular mixtures subject to vibration, Powder Technology, **vol.382**, 2021, pp. 107-117.

[4]. *B. B. Dai, W. H. Yuan, J. K. Liu, et al.* Estimating the segregation of a granular bed subjected to vibration in various modes, Advanced Powder Technology, **vol. 32**, Issue 5, 2021, pp. 1450-1462.

[5]. *X. W. Wang, G. H. Zhu, C. Yu, et al.* Research and analysis of vibration parameters of vibratory bed surface based on EDEM. Coal Engineering, **vol. 50**(07), 2018, pp. 119-123. (in Chinese)

[6]. *Y. J. Liu, P. C. Li, J. L. Xu, et al.* Parameter optimizing settings of high frequency vibration trough in tobacco drying. Tobacco Science & Technology, **vol. 53**(3), 2020, pp. 97-101, 123. (in Chinese)

[7]. *P. J. Su, Z. G. Cao, J. R. L. Yasenjiang, et al.* EDEM numerical simulation and analysis of vibrating feeder feeding. Coal Mine Machinery, **vol.42**(10), 2021, pp. 77-79. (in Chinese)

[8]. *X. X. Kong, C. Z. Chen, B. C Wen.* Dynamic and stability analysis of the vibratory feeder and parts considering interactions in the hop and the hop-sliding regimes. Nonlinear Dynamics, **93**, 2018, pp. 2213-2232.

[9]. *Z. M. Boriskina, O. O. Baryshnikova.* The mathematical model of motion of particles in vibrating conveyors. Int J Mech Eng Robot Res, **9**, 2020, pp. 76-79.

[10]. *D. Gelnar, R. Prokeš, L. Jezerska, et al.* Wood pellets transport with vibrating conveyor: experimental for DEM simulations analysis. Scientific Reports, **11(1)**: 2021.

[11]. *C. Singh, M. L. Chandravanshi.* Dynamic analysis and performance assessment of a vibratory feeder for different motor positions on trough. Mechanics Based Design of Structures and Machines, **51(11)**, 2023, pp. 6453-6470.

[12]. *V. Korendiy, O. Kachur, I. Hurey, et al* “Modelling and experimental investigation of the vibratory conveyor operating conditions,” Vibroengineering PROCEDIA, **vol. 47**, Dec. 2022, pp. 1–7.

[13]. *E. Simsek, S. Wirtz, V. Scherer, et al.* An Experimental and Numerical Study of Transversal Dispersion of Granular Material on a Vibrating Conveyor, Particulate Science and Technolo gy, **26**, 2008, pp.177-196.

[14]. *C. Tudor, P. Mihai, V Gheorghe*. A developing a mathematical model for simulating the seed s separation process on the plane sieves. U.P.B. Sci. Bull., Series D, **vol. 71**, Iss. 3, 2009, pp. 17-28.

[15]. *L. W. Wu, L. P. Zeng, Z. H. Wan, et al*. Modeling and vibration characteristics of a DMF base d on equivalent linearization method. U.P.B. Sci. Bull., Series D, **vol. 84**, Iss. 4, 2022, pp. 3-15.

[16]. *F. Ma, H. Wu*. Key structure innovation and optimization design of bucket levator. Manufact uring Automation, **vol. 41(01)**, 2019, pp. 127-129.(in Chinese)

[17]. *H Yuan, S. Liang, J Wang, et al*. Numerical Simulation and Analysis of Vibrating Rice Filling Based on EDEM Software. Agriculture. **12(12)**, 2022.

[18]. *S. Sarangi, K. Thalberg, G. Frenning*. Effect of Fine Particle Shape on the Stability and Performance of Adhesive Mixtures Intended for Inhalation. Powder Technol, **385**, 2021, pp. 299–305.

[19]. *J. R. Wang, Y. Y. Huang*. Influence of threshing machine’s threshing parameters on threshing quality based on EDEM. Agricultural Equipment & Vehicle Engineering, **vol. 60(6)**,2022, pp. 90-92,97.(in Chinese)

[20]. *X. D. Shi, L. F. Qian, Y. D. Xu, et al*. Screening Performance Indexes and Screen Surface Configuation of Discrete Type Vibrating Screen, Metalmne, **(12)**, 2008, pp. 113-115.(in Chinese)

[21]. *A. Y. Liu, S. Liu, Z. G. Pan*. Numeriacl simulation of movement of solid particles in a vibrating feeder. Journal of University of Chinese Academy of Sciences, **(1)**, 2002, pp. 35-43.(in Chinese)

[22]. *F. Kipriyanov, Y. Plotnikova*. Application of Mathematical Methods to Evaluate Vibration Conveyor. International Scientific Conference on Agricultural Machinery Industry "Interagromash". Cham: Springer International Publishing, 2022, pp. 1621-1629.

[23]. *C. C. Nie, Z. N. Han, Y. Zhao, et al.* Optimal design of mixing blade based on EDEM numerical simulation. Machinery Design & Manufacture, **(4)**, 2019, pp .17-20,25.(in Chinese)

[24]. *J. S. Liu, C. Q. Gao, Y. J. Nie, Bo Yang, et al*. Numerical simulation of Fertilizer Shunt-Plate with uniformity based on EDEM software, Computers and Electronics in Agriculture, **vol. 178**, 2020.