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Parameter Design and Simulation Research on Wind Vibration Sorting Device Structure of Waste Plastics

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Abstract: Winnowing and vibration sorting device were designed in this study and waste plastics separation dynamics equations were established, sorting device parameter so can be optimized and a reasonable size of structure which as sorting device drive mechanism was ascertained. Vibration device analysis model was established in the ADAMS, then through the motion simulation analysis got all kinds of waste plastics movement displacement locus and spacing diagram on the screen surface, so the motion parameters was optimized. Waste plastics composite separation device was developed, what improved the precision and efficiency of plastic separation.

Key words: Waste plastics, wind separation, vibration sorting, simulation

INTRODUCTION

The current waste plastics separation technology (Dan *et al*., 2006; Tian-Fu, 2004) is too complicated or high cost, our group put forward plastic composite separation technology from environmental and economic aspects. This technology is first through the air separation then through vibration sorting method, that finally waste plastic is achieved best separation.

After winnowing, plastic on the sieve surface of smaller spacing, so in this study, through comprehensive analysis, offset slider-crank (Jia-Di, 2003) was designed as drive mechanism, Polyethylene (PE), Polyvinyl Chloride (PVC) and Polyester (PET) plastic (Min, 2012) were chosen as the depth separation target which have the most content in the waste plastic. Simulation analysis of the three kinds of waste plastics in the vibration system (Lian-Bo, 2011; Haipei *et al*., 2011) was conducted in this study. This study research work provides the technical support for our country plastic separation technology.

THE STUDY OF WINNOWING DEVICE PARAMETER

Under the action of the wind blowing, the separation of different plastic can be achieved, due to the different plastic density its falling distances are also different, waste plastic sorting device as shown in Fig. 1. The dynamic equations of sorting can be established and each single factor can be studied its effect level on the waste plastics separation, so that the plastics can be separated as the ideal trajectory and a sorting equipment of good effect can be designed.

Dynamics equation of waste plastics separation: Take the three broken kinds of waste plastic mixture as the particle that under the action of airflow, establish dynamics equation. In order to analysis its movement, first establish the coordinates, plastic into the inclined airflow as the coordinate origin, the vertical direction as x axis, the horizontal direction as y axis and air flow and horizontal angle is α, speed is $\overline{V}$, the material and the vertical angle is β, the initial velocity is $\overline{V_0}$ (Fig. 2). If the plastic absolute speed is $\overline{V_a}$ and the $\overline{V}$ as air traction speed[7], then the relative motion velocity for plastic is:

$$\overline{V_r} = \overline{V_a} - \overline{V} \tag{1}$$

For ease of calculation, the equation is introduced into a plastic suspension speed of $V_{L'}$, to replace the floating coefficient ω. When the airflow is vertically upward, so that the material is suspended in the air, air flow to the material force and gravity balance, i.e. $F = \omega m V_{L'}^2 = mg$, $\omega = g / V_{L'}^2$.

Air force $\vec{F} = -mg / V_{L'}^2 V_r \overline{V_r}$ of the material opposite the $\overline{V_r}$ direction, establish the dynamic differential equations of planar vector form:

$$-\frac{mg}{V_{L'}^2} V_r \overline{V_r} + \overline{mg} = m \frac{\overline{dv_a}}{dt} \tag{2}$$

Converted into analytic type differential equations:

$$\begin{cases} -\dfrac{g}{V_{L'}^2} V_r V_{rx} + g = \dfrac{dV_{ax}}{dt} \\ -\dfrac{g}{V_{L'}^2} V_r V_{ry} = \dfrac{dV_{ay}}{dt} \end{cases}$$

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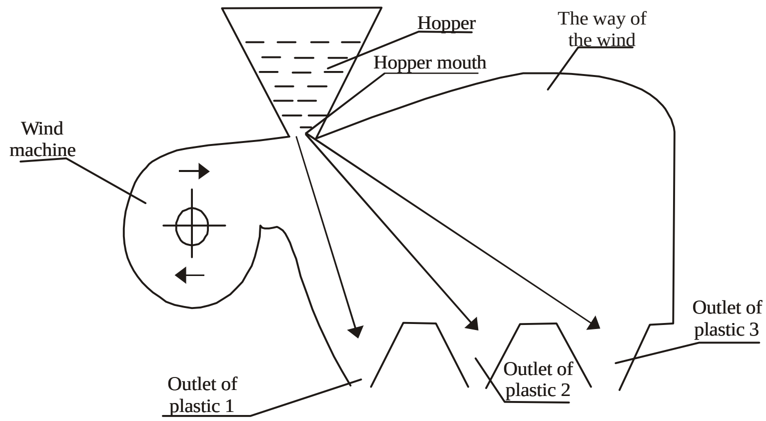

Fig. 1: Separation process of winnowing device

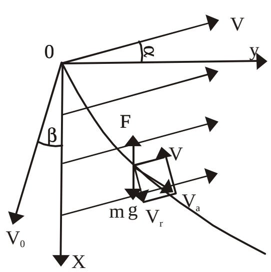

Fig. 2: Analysis of force and speed of plastics

According to Fig. 2 vector diagram of the V_x and V_y can be expressed as:

$$\begin{cases} V_x = V\cos\left|\alpha + \dfrac{\pi}{2}\right| = -V\sin\alpha \\ V_y = V\sin\left|\alpha + \dfrac{\pi}{2}\right| = -V\cos\alpha \end{cases}$$

V_{rx} and V_{ry} can be expressed as:

$$\begin{cases} V_{rx} = V_{ax} - V_x = V_{ax} + V\sin\alpha \\ V_{ry} = V_{ay} - V_y = V_{ay} + V\cos\alpha \end{cases}$$

So it can be:

$$\begin{cases} f_1(V_{ax}, V_{ay}) = \dfrac{dV_{ax}}{dt} = -\dfrac{g}{V_{L'}^2}\sqrt{(V_{ax}+V\sin\alpha)^2+(V_{ay}-V\cos\alpha)^2}\,(V_{ax}+V\sin\alpha)+g \\ f_2(V_{ax}, V_{ay}) = \dfrac{dV_{ay}}{dt} = -\dfrac{g}{V_{L'}^2}\sqrt{(V_{ax}+V\sin\alpha)^2+(V_{ay}-V\cos\alpha)^2}\,(V_{ay}-V\cos\alpha) \end{cases} \tag{3}$$

Plastic initial velocity:

$$\begin{cases} V_{ax0} = V_0\cos(2\pi-\beta_0) = V_0\cos\beta_0 \\ V_{ay0} = V_0\sin(2\pi-\beta_0) = -V_0\sin\beta_0 \end{cases}$$

Velocity and displacement of plastic particle: Differential Eq. 3 can only use the numerical method for the original function. With time Δt step, V_{axn}, V_{ayn} as initial speed of two-dimensional component in Δt time, to find after time Δt approximate speed:

$$\begin{cases} V_{ayn+1}^* = V_{ayn} + \Delta t f_1(V_{axn}, V_{ayn}) \\ V_{ayn+1}^* = V_{ayn} + \Delta t f_2(V_{axn}, V_{ayn}) \end{cases} \tag{4}$$

V_{axn+1}^*, V_{ayn+1}^* is Δt time velocity of 2D component approximation, its value is the rectangle area that initial velocity as high, Δt time for the width, the accuracy is not high, in order to improve the precision, Eq. 4 was corrected, amended velocity approximation is:

$$\begin{cases} V_{axn+1} = V_{axn} + \Delta t/2(f_1(V_{axn}, V_{ayn}) + f_1(V_{axn+1}^*, V_{ayn+1}^*)) \\ V_{ayn+1} = V_{ayn} + \Delta t/2(f_2(V_{axn}, V_{ayn}) + f_2(V_{axn+1}^*, V_{ayn+1}^*)) \end{cases} \tag{5}$$

Equation 5 approximate values is the trapezoidal area that after integral which initial acceleration as upper bottom and acceleration after Δt time as the lower bottom of the trapezoidal area, obviously its precision raised a level than Eq. 4.

In the short Δt time, its speed can be regarded as the average speed which initial velocity and the end is the average speed, so plastic displacement in Δt time is:

$$\begin{cases} \Delta x_n = (V_{axn+1} + V_{axn})\Delta t/2 \\ \Delta y_n = (V_{ayn+1} + V_{ayn})\Delta t/2 \end{cases}$$

Thus the plastic displacement is:

$$\begin{cases} x_{n+1} = x_n + \Delta x_n \\ y_{n+1} = y_n + \Delta y_n \end{cases}$$

Optimization value of the plastic separation parameter: Through the calculation, analysis to get

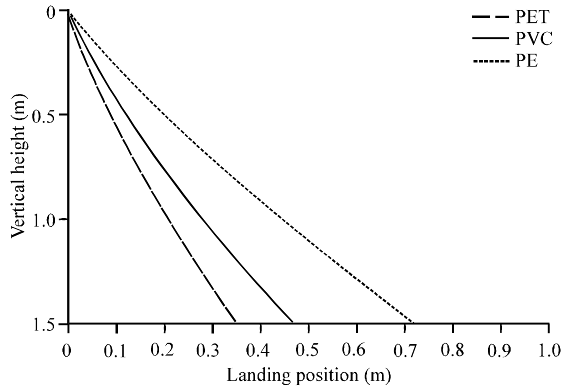

Fig. 3: PET, PVC, PE plastic trajectory optimization parameters

PE, PVC and PET plastic suspension velocity, respectively 2.932, 3.742 and 4.366 m $\sec^{-1}$. Sorting room height is 1.5 m, length is 1 m. The target is to make PET, PVC and PE landing position respectively from the separation chamber left about 0.35, 0.5 and 0.7 m. Air flow rate V and its direction angle α, plastic initial velocity V_0 and its direction angle β values range are:

$$0 \leq V_0 \leq 5 \text{ m/s } 1{,}0 \leq V \leq 20 \text{ m/s}$$
$$0 \leq \alpha \leq 50°, 0 \leq \beta \leq 10°$$

Material optimal trajectory as shown in Fig. 3 which though MATLAB programming gotten, as can be seen from the graph, PET placement in distance sorting chamber bottom is about 0.35 m, PVC placement at a distance of separation chamber bottom is about 0.47 m, PE plastic landing at a distance from the separation chamber bottom is about 0.72 m position, here its material initial speed is 0.122 m $\sec^{-1}$, angle is 9.41°, airflow velocity is 1.785 m $\sec^{-1}$, angle is 6.22°. Three kinds of plastic track completely consistent with the expected optimization target.

SIMULATION RESEARCH ON VIBRATION SORTING DEVICE

Design of drive mechanism: Drive mechanism is crank slider mechanism (Qi-Dong and Zhi-Guo, 2011; Bin *et al*., 2006) this mechanism can be very good to meet the requirement of vibration (Liu, 2011) separation and has the features of simple structure, easy fabrication etc. The general design of the mechanism is given prior stroke ratio k and maximum stroke S before, then to obtain the crank and connecting rod related dimensions. In order to save material, crank length was simplified by motor rotating point position, the rotary was drilled holes in different position beforehand. One of the holes was chosen as the length of the crank, as known k and α, the S values range can be determined, a reasonable size can be chosen from it, so e and the connecting rod b sizes can be seek offset (Fig. 4).

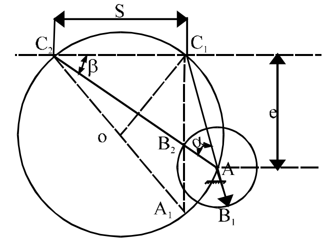

Fig. 4: Crank slide block structure and its motion diagram

The known conditions are: crank length α = 10 mm, stroke ratio k = 1.1, α = 180°(k-1)/(k+1).

In the movement continuity that offset is not more than A_1C_1 and ΔAC_1C_2 existing conditions, S size should meet the following range:

$$2a \leq S \leq \sqrt{\frac{8a^2\cos^2(\alpha/2)}{1-\cos\alpha}}$$

The calculation is 20≤S≤260.

From the graph of the geometrical relationship to know:

$$2R = \frac{S}{\sin\alpha} \tag{6}$$

$$AC_1 = b - a = 2R\sin\beta \tag{7}$$

$$AC_2 = a + b = 2R\sin(\alpha+\beta) \tag{8}$$

$$e = (a+b)\sin\beta \tag{9}$$

By Eq. 7 and 8 formula to get:

$$a = R[\sin(\alpha+\beta) - \sin\beta] \tag{10}$$

$$b = R[\sin(\alpha+\beta) + \sin\beta] \tag{11}$$

From Eq. 9 to get:

$$a + b = \frac{e}{\sin\beta} \tag{12}$$

Put Eq. 6, 10, 11 into Eq. 12 formula that:

$$e\sin\alpha = S\cdot\sin\beta\cdot\sin(\alpha+\beta) \quad (13)$$

$$\beta = [\arccos(\cos\alpha - 2e\sin\alpha / S)]/2 - \alpha/2 \quad (14)$$

Thus from Eq. 14 formula to get:

$$\begin{cases}\sin\beta = \sqrt{(1-\cos\alpha + 2e\sin\alpha/S)/2}\cos(\alpha/2) - \sqrt{(1+\cos\alpha - 2e\sin\alpha/S)/2}\sin(\alpha/2)\\ \sin(\alpha+\beta) = \sqrt{(1-\cos\alpha + 2e\sin\alpha/S)/2}\cos(\alpha/2) + \sqrt{(1+\cos\alpha - 2e\sin\alpha/S)/2}\sin(\alpha/2)\end{cases} \quad (15)$$

Put Eq. 6, 15 into Eq. 10 get:

$$e = \frac{S^2(1+\cos\alpha) - 8a^2\cos^2(\alpha/2)}{2S\sin\alpha} \quad (16)$$

Put Eq. 6, 15 into Eq. 11 to get:

$$b = \frac{S}{2\sin(\alpha/2)}\sqrt{\frac{S - S\cos\alpha + 2e\sin\alpha}{2S}} \quad (17)$$

Put Eq. 16 into 17 to get:

$$b = \frac{1}{2\sin(\alpha/2)}\sqrt{S^2 - 4a^2\cos^2(\alpha/2)} \quad (18)$$

The value of S is determined as 30, it with b value are substituted into Eq. 16 and 18, to get connecting rod and offset sizes, respectively are 150 mm and 111 mm.

The establishment of simulation model: According to the calculation results, vibrating screen body model was built in UG, then geometric model was derived as "Parasolid" format, this format geometric model was finally put into Adams (Engao *et al*., 2012) motion analysis software.

First, by edit each of its component attribute, or in simulation it can be get error. The sieve body components material property is set to "steel", plastic property settings can by selecting the "Geometry and Density" option to set plastic density. In addition, in order to identify and control all of the components, each component can be modified on the color attribute information. Second, add constraint for each component after attribute definition. It should be noted that friction addition of translational joint that between screen surface and the plastic and the modification of friction parameters. Finally, Rotational joint motion can be built after constraint addition and corresponding editor can be done in driving edit box. After adding constraints and drive, the geometry of the model in the angle of the screen surface there have four nuts on the screw that can adjust the angle of the screen surface transverse and longitudinal direction.

Post-processing and results analysis: Select the default types and the calculation of simulation time in interactive simulation control, due to the driver of the crank speed slants big, increase the step of the simulation and the simulation calculation start from static balance. After the simulation, then check the simulation curve of all components in ADAMS/View. Find plastic components in the data source and to get the curve of the information that useful.

In the actual mixture plastic screening process, each particle plastic film stress situation is more complex, also cannot be predicted, but all kinds of plastic sports trends are consistent, so in a variety of plastic sports simulation creates a film as the simulation object. According attribute parameter of the mixed plastics, the plastic films are set respectively corresponding to it, all kinds of plastic displacement curves under different rotational speed that on the transverse cross section can be gotten, as shown in Fig. 5.

In Fig. 5a and b, respectively plastic films in the direction of X axis displacement curve which through experience motor angular speed are 960°/s and 1080°/s, respectively. The curve in the figure from top to bottom, respectively represent three kinds of plastics, PE, PVC and PET. On the two picture contrast, shows the motor speed increases, all kinds of plastic speed becomes larger which on the sieve surface cross section, but separation distance between them have no obvious differences. From the graph can also be identified the specific position that the films leave screen surface, this is provided a basis for the design of the plastic box. The motor speed to decrease or increase have what effect on the various plastic, simulation analysis under the motor speed of 930°/s and 1440°/s were conducted below.

In Fig. 5c-d, respectively plastic film simulation result that the motor speed are 930°/s and 1440°/s, respectively. Motor speed at 930°/s, although PE and PVC separation distance is large enough, but separation distance between PVC and PET plastic is not obvious in a relatively short time and PE plastic has the trend to stop the movement, if the speed is reduced, easily lead to three plastic stop motion due to inertia force inadequacy, can not realize distance increases between three kinds of plastic. Motor speed at 1440°/s, three kinds of plastics slipped out of the screen surface in 3 sec time and the separation of each kind of plastic between the interval is small, the amplitude is smooth, even if a long time interval between them will not be changed.

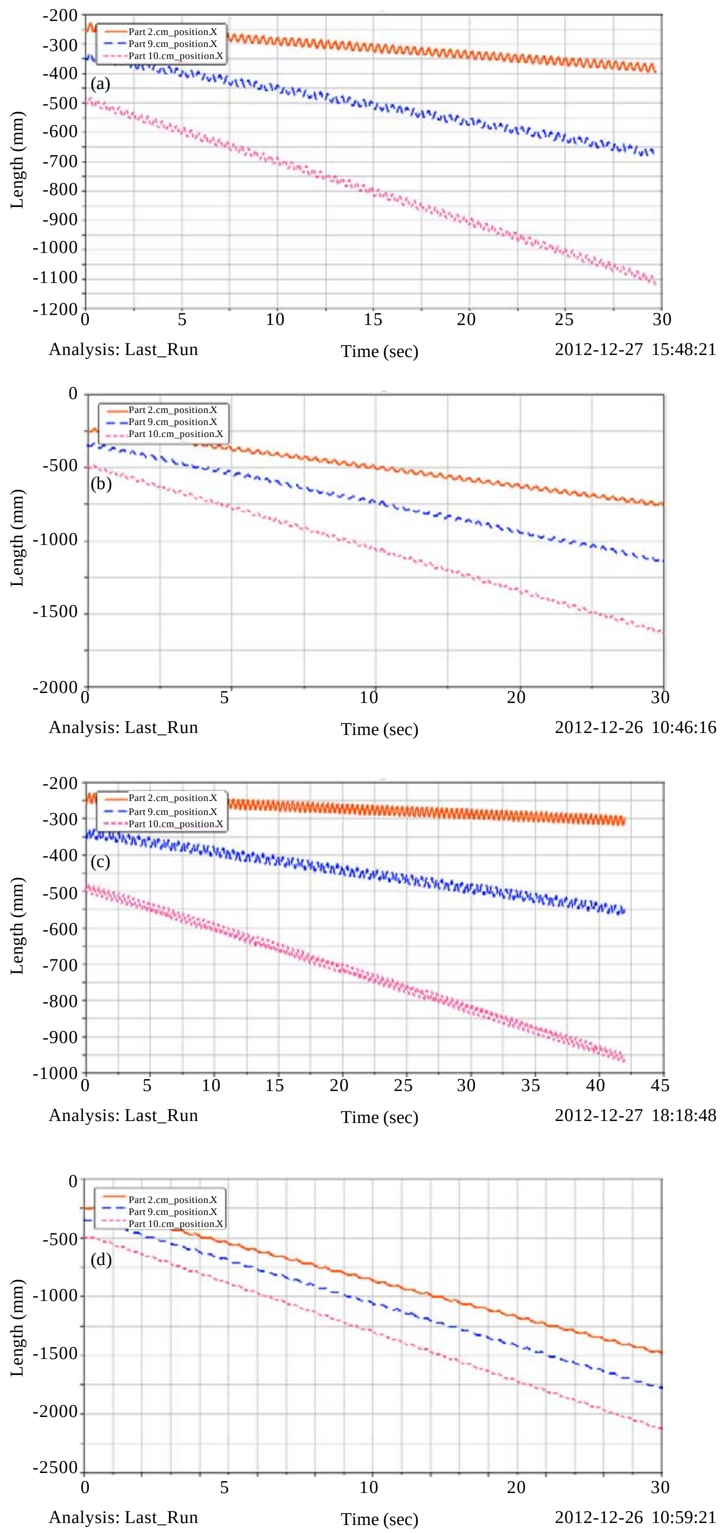

Fig. 5(a-d): Curve of displacement on the horizontal section (a) Plastic movement curve under 960°/s, (b) Plastic movement curve under 1080°/s, (c) Plastic movement curve under 930°/s and (d) Plastic movement curve under 1440°/s

Fig. 6: The Winnowing and vibration sorting prototype

To sum up, the motor speed is not high separation effect is better, not rotate speed is low with good separation results, but only when the motor speed is adjusted to a segment. From the above simulation can be drawn when the rotational speed of the motor is controlled at 1080°/s, all kinds of plastic can be separated and separation distance are around 400 mm.

Development of a prototype: According to the theory and analysis of simulation results, the prototype was developed and as shown in Fig. 6.

The working principle of entire device is: a collection of soft packaging waste plastic mixture which after crushing are delivered to the separator inlet through is located at the lower end of the feed port, between them vibration feeder conveyor; air outlet of the centrifugal fan is a wind direction regulating device which can be arbitrarily adjusted direction angle. Plastic mixture can do parabolic movement under wind action and eventually scattered in the vibration bed. Motor movement then drive the vibrating bed on the guide rail to do reciprocating motion through the crank slider mechanism. Vibration bed are respectively provided with angle regulator, so we can adjust bed surface with vertical and horizontal angle, the plastic mixture in the vibration process are separated through the various forces and the upper side has plastic collector. Finally separated plastic mixture respectively fall into different collector and the sorting process end.

Innovation is as follows:

- Winnowing and vibration sorting device were designed
- Sorting device parameter were optimized
- A reasonable size of structure which as sorting device drive mechanism was ascertained
- The precision and efficiency of plastic separation were improved

CONCLUSION

Crank slide block was decided as the driving mechanism and its size of each component was calculated. Through ADAMS simulation has got plots about all kinds of waste plastics in screen motion trajectory and them distance, obtained the crank adjustable range, provides the theoretical basis for the parameters adjustment that the equipment in practical work and so a waste plastic composite sorting device was developed.

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