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To cite this article: W Liu *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **220** 012036

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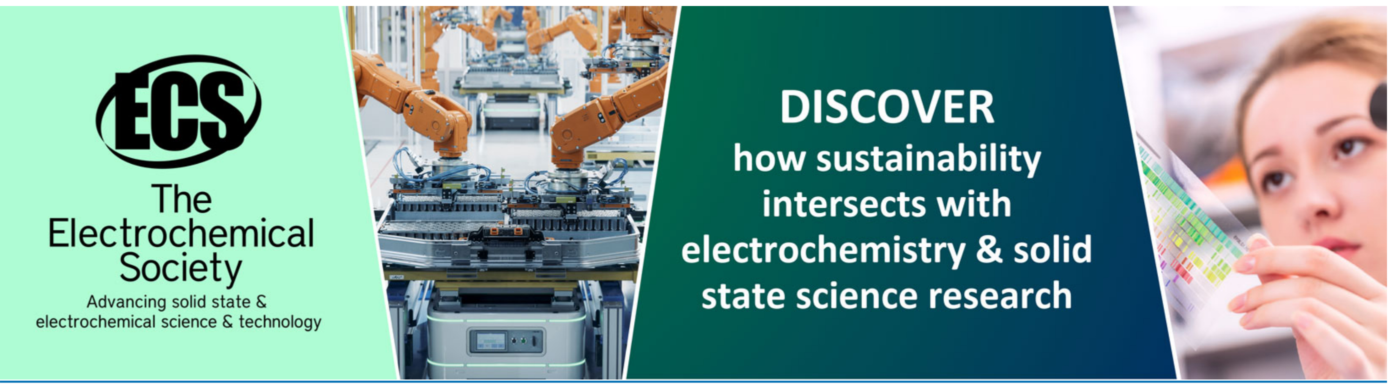

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IOP Conf. Series: Materials Science and Engineering **220** (2017) 012036 doi:10.1088/1757-899X/220/1/012036

Co-simulation on vibration characteristics of uniaxial shaker based on AMESim and ADAMS

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Abstract. In this paper, we propose a selection method of the increased amplitude stability parameter for the unstable motion problem of the uniaxial shaker before its stable operation. On the basis of single-axis shaker dynamics equations, an ADMAS and AMESim combined simulation model is established. According to this model, the vibration characteristics under different parameters are solved by using the control variate method. The simulation results show that the motor speed, the eccentric mass and the inclination of screen surface are the three main factors which affect work starting state of uniaxial shaker. The working efficiency of uniaxial shaker is controlled by the motor speed while the amplitude is affected by the eccentric mass. Moreover, the inclination of screen surface plays a decisive role in the distribution of the vibration track before uniaxial shaker reaching the stable operation state. The relatively stable movement is obtained by optimizing the parameters, which provides a new way to improve the stability of uniaxial shaker.

1. Introduction

Uniaxial shaker[1] widely used in modern industry, its controllability projectile angle, adjustable amplitude, diversified hierarchical levels and other screen surface vibration characteristics of the vibrating screen performance play a decisive factor. Shaker work, if the shaker vibration amplitude is too large, the body will lead to instability, increasing the impact on the ground; and if the vibrating screen to reach a stable state for a long time, will affect the life of the body. Li Bin-hui[2] adopts PID control strategy to optimize the parameters, to achieve the stability of the control, but this method is complicated, and the workload of the experiment is large when the parameters are optimized; Zhang La-la[3] discusses the influence of amplitude, throwing index, screen angle on the average speed of screening material particles, the speed change reflects the fluctuation amplitude from the side, but in practice, these three parameters can not be precise control, parameter selection is limited; Chen Xiao-qiang[4] analysis of the response of a shaker system, through numerical calculation and experimental procedures modified exciting force, stable amplitude ideal, computational complexity theory, applicable to verify the optimized parameters results. In fact, the time from start to hold steady state is the key point to study the vibration characteristics of the vibrating screen, and the output vibration direction of the ellipse can be more intuitive to analyze the stability of the amplitude.

This research is based on the dynamic equation of uniaxial shaker, and the AMESim and ADAMS software are combined co-simulation [5,6]. A control system is established in AMESim, and the mechanical vibration system is established in ADAMS. The speed of the drive motor, the quality of the eccentric block and the inclination angle of the screen face are simulated. According to the

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displacement time curve, the eccentric block angular velocity curve and the displacement synthesis curve, the steady state of the vibrating screen is analyzed, and it introduced the concept of throwing index and verify, then compare the simulation results under different conditions, get the factors that affect the vibration state, optimize the structure of the vibrating screen, and output the optimized curve.

2. Structure and working principle of uniaxial shaker

The basic structure of uniaxial shaker is shown in figure 1. Mainly consists of vibration exciter (including 2 sets of eccentric block, rotating shaft, bearing), box, screen surface, support springs, bearings, conveyor belt (or coupling), vibration motor and other parts of the vibration. Wherein, the eccentric block is fixed with rotating shaft and the motor transmits energy through the transmission belt, the eccentric device of uniaxial shaker obtains the rotational speed, thereby generating the exciting force and driving the box body under the action of the supporting spring, and making the material entering the sieve surface to generate vibration and reaching the screening effect.

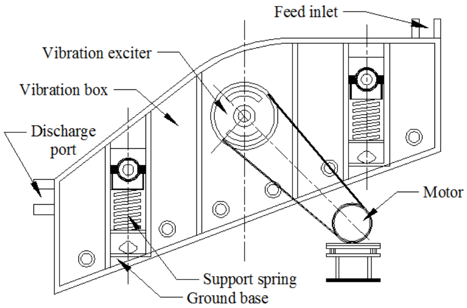

Figure 1. Schematic diagram of single shaft vibrating screen.

3. Modeling of uniaxial shaker

3.1. Mathematical modeling of uniaxial shaker

According to the Darren Bell theorem of the motor rotor, the dynamic equations of the vibrating screen mainly include: the characteristics of the vibration motor, load torque, friction torque, etc.

According to the electric drive theory, the practical expression of the mechanical characteristics of the exciting motor is [7]:

$$T = \frac{2T_m}{\frac{s}{s_m} + \frac{s_m}{s}} \tag{1}$$

Among: $s = \frac{n_0 - n}{n_0}$

Where: T_m —Maximum torque of vibration motor, N.m; T —Motor output torque, N.m; s —The vibration motor slip; s_m —The maximum vibration motor slip; n_0 —Synchronous speed of vibration motor, r.s^{-1}; n —Vibration exciter speed, r.s^{-1}, $n = \frac{\omega}{2\pi}$; ω —Vibration exciter angular velocity, rad.s^{-1}.

According to the single shaft driving device, the vibration of the axis line direction and the friction force between the vibration exciter and the box body are not considered, the gravity of the eccentric block provides energy, prompting the vibration exciter rotated around the axis line to obtain the track motion. Vibrating screen to overcome the gravity of the eccentric block to produce the load torque of[8]:

$$T' = \sum_{i=1}^{4} m_i r_i g \sin\varphi \tag{2}$$

Where: φ—Eccentric block angular displacement of rotating shaft, rad; $\sum_{i=1}^{4} m_i r_i$—product of mass radius of four eccentric blocks, $\sum_{i=1}^{4} m_i$ is the total mass of four eccentric blocks, kg, i=1, 2, 3, 4; g—Acceleration of gravity, 9.8m.s^{-2}.

In the study of the characteristics of the excitation motor drive system, the friction torque of the motor rotor is [9]:

$$T_f = T_v + f\omega + \sum_{i=1}^{4} m_i r_i f \omega^2 \frac{d}{2} \tag{3}$$

Where: T_v—Motor rotor constant resistance moment, N.m; f—Friction coefficient; d—bearing bore diameter, m.

Combined with the above parameters, the control equation of the vibrating screen drive system can be obtained:

$$\frac{2T_m n_z}{\dfrac{n_0\pi - 30\omega n_z}{n_0 \pi s_m} + \dfrac{n_0 \pi s_m}{n_0\pi - 30\omega n_z}} - T_v - f\omega - \frac{1}{2}\sum_{i=1}^{4} m_i r_i f \omega^2 d - \sum_{i=1}^{4} m_i r_i g \sin\omega t = J\frac{d\omega}{dt} \tag{4}$$

Where: n_z—Conveyor belt between the motor and the vibrator; J—Moment of inertia, kg.m^2.

By the dynamic equation, the research on the vibration characteristics of vibrating screen contains the amplitude, frequency, the angle of the screen surface and so on[10]. In Liu Huan-sheng's paper[11], it obtained a comprehensive evaluation index, that is throwing index, it is used in the definition of single axis vibrating screen is:

$$D = \frac{\omega^2 H \sin(\alpha + \beta)}{g\cos\beta} \tag{5}$$

Where: H—Vertical component of amplitude, m; α—The initial projection angle, rad; β—Screen surface inclination, rad.

3.2. Vibration system model of uniaxial shaker based on ADAMS

According to the working principle of uniaxial shaker[12], the simple vibration system model is established by UG8.0 and imported into ADAMS[13], as shown in Figure 2. The inside of the screen box is simplified, and the quality is controlled by the cylinder on both sides of the symmetrical distribution. At the same time, the connection between the box and the vibration exciter is connected with the rotary pair, the support is connected with the four supporting springs, and the bottom of each bearing and the ground are fixed with a fixed pair.

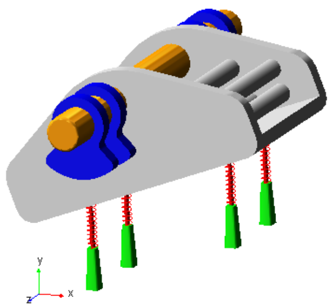

Figure 2. Prototype model of single axis vibrating screen.

In ADAMS, the model direction is established as shown in figure 2, the direction of gravity is the negative direction of the Y axis, and the Z direction is parallel to the horizontal direction of the cylinder in the box, and the X direction is perpendicular to the horizontal direction of the cylinder.

Some material properties of vibrating screen are defined in table 1.

Table 1. Material properties of vibrating screen

Name	Density[kg.m^3]	Name	Spring coefficient[N.m]	Damping coefficient[N.s.m^{-1}]
Box	8545.0	Support spring	700	0.58
Eccentric block	1.9222E+04	X direction bushings force	5500	0.06
Rotary shaft	1.9222E+04	Z direction bushings force	450000	0.68

Due to the joint simulation, ADAMS needs to get the torque energy from AMESim, while the angular velocity of the eccentric device system vibration transmitted to the AMESim, so as to exchange the simulation data, the study needs to establish the input and output variables, the specific content as shown in table 2.

Table 2. ADAMS input and output variable table

Variable name	Variable type	Physical meaning
Torque	Output variable	Motor torque, acts on the exciter
AngularV	Input variable	the angular velocity of Shaker eccentric
XDis	Input variable	X direction displacement of vibrating screen box
YDis	Input variable	Y direction displacement of vibrating screen box

3.3. Model of uniaxial shaker control system based on AMESim

According to the dynamic equation, the control system model based on AMESim[14] is established in Figure 3. AMESim is mainly to provide torque energy for the ADAMS vibration system, at the same time to receive the angular velocity of its output, and feedback to the torque, forming a closed loop. According to the working principle of the shaker, the system is divided into the vibration system and the control system. The joint simulation diagram is shown in Figure 3.

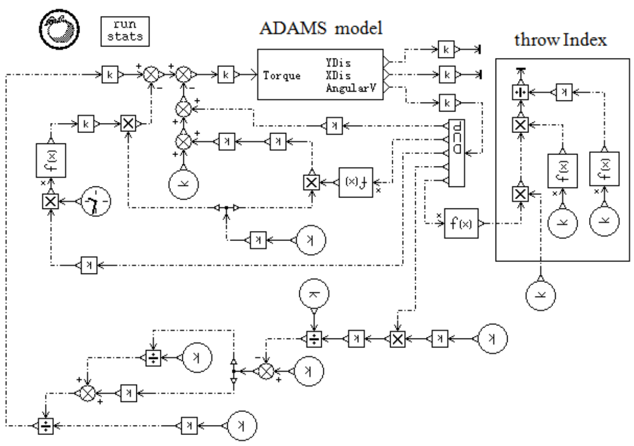

Figure 3. Joint simulation of AMESim and ADAMS.

The main parameters in AMESim are set as shown in table 3:

Table 3. Main parameter settings for AMESim

Parameter name	Parameter character	Value	Units
Motor maximum torque	T_m	3	N.m
The maximum motor slip	s_m	0.152	/
Conveyor belt transmission ratio	n_z	0.8	/
Motor rotor constant resistance moment	T_v	0.01	N.m
Bearing bore diameter	d	0.3	m
Friction coefficient	f	0.002	/

4. Sections, subsections and subsubsections

To ensure the consistency of the two software, the interface of the two model is adjusted by several gain modules. The simulation is set to Discrete co-simulation, The two software respectively solve the problem, develop the advantages of each solver and exchange the obtained data [15].

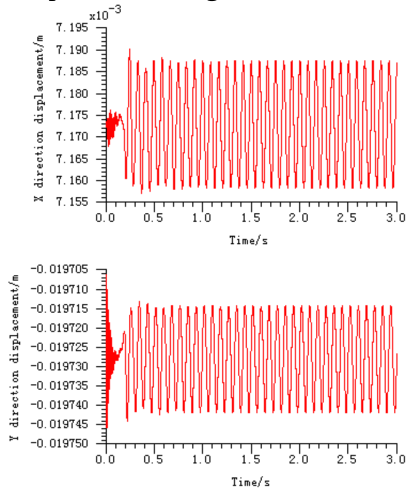

Figure 4. X and Y direction displacement curves of single axis vibrating screen.

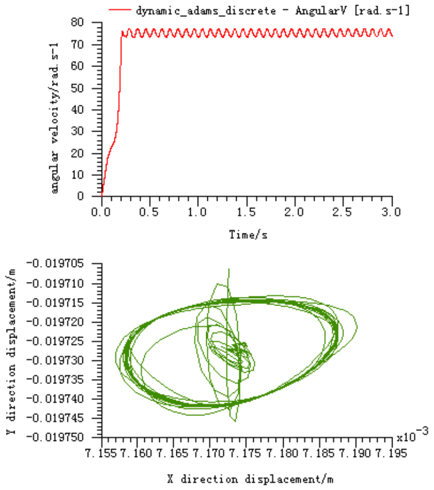

Figure 5. Velocity and displacement curve of eccentric angle.

Setting the time interval is 0.001s, the system simulation time is 3s, the step size is 0.0005s. Setting the motor speed is 900 r.min^{-1}, the angle between the screen surface and the ground is 20^{o}, the material density and size remain unchanged. The displacement time curve of the X and Y direction of the vibrating screen, the change curve of the angular velocity of the eccentric block and the trajectory of the displacement are shown in Figure 4 and 5.

By the graph, you can see that vibrating screen in the direction of Y and X made positive cosine curve movement after reaching a stable state, in a short period of time can be achieved basically stable, the formation of elliptical trajectory, the stability is better. At the same time, the size of the angular velocity is stable and the regularity of the circulation is maintained.

5. Simulation of factors affecting vibration characteristics of uniaxial shaker

Through the analysis and experiment of initial projectile angle, the initial projection of uniaxial shaker angle between 70^{o}~74^{o}[11]. This study set the projection angle $\alpha = 72^{o}$. In guarantee the normal work of vibrating screen case, throwing index size is generally between 3~5. From the definition of throwing index can know its size and amplitude, eccentric angular velocity, the inclination is related, the specific model is shown in figure 3. In the experiment, study on the effect of motor speed, eccentric quality, screen angle and other factors change on the throwing index, so as to optimize the internal structure of vibrating screen, achieve the ideal screening effect.

5.1. Effect of motor speed

For different motor speed simulation, the results are as shown in figure 6.

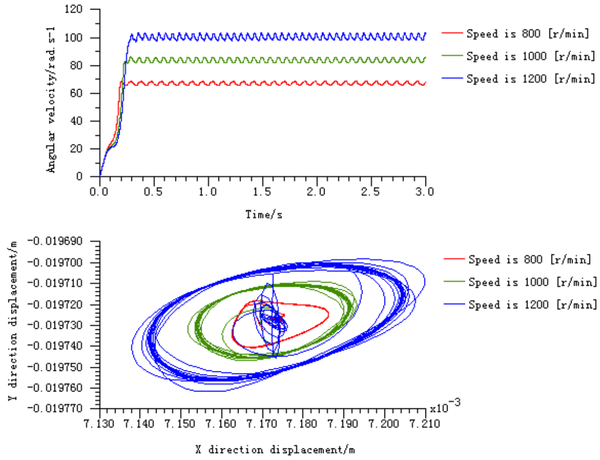

Figure 6. Effect of motor speed on the throwing index.

The speed of the three simulations is 800r.min^{-1}, 1000r.min^{-1}, 1200r.min^{-1}. As can be seen from Figure 6, the motor speed determines the angular speed of the eccentric device, when the speed increases, the formation of the elliptical trajectory more standardized, the time corresponding to the steady state of the vibrating screen is increased, and the numerical value of angular velocity and the amplitude of vibration are also larger. Comparison of the three groups of simulation images, you can get: when the speed is greater, the same time, the formation of the trajectory is more intensive, the better the efficiency of the work. Three sets of vertical component data are obtained by simulation: 2.15×10^{-5}, 3.61×10^{-5}, 5.48×10^{-5}. Using the formula (5) can be calculated from their throwing index are: 1.05, 2.78, 5.95. According to the requirements of the throwing index, we can see: with the increasing of speed, throwing index increased. When the speed is less than 800r.min-1 and greater than 1200 r.min-1, the throwing index does not meet the conditions, so the appropriate rotational speed in the range of 800~1200 r.min-1.

5.2. Effect of eccentric mass

For different eccentric mass, because the eccentric device size in ADAMS is fixed, for the sake of simplicity, the quality can be changed by changing the properties (density) of the material, the simulation results are obtained as shown in figure 7.

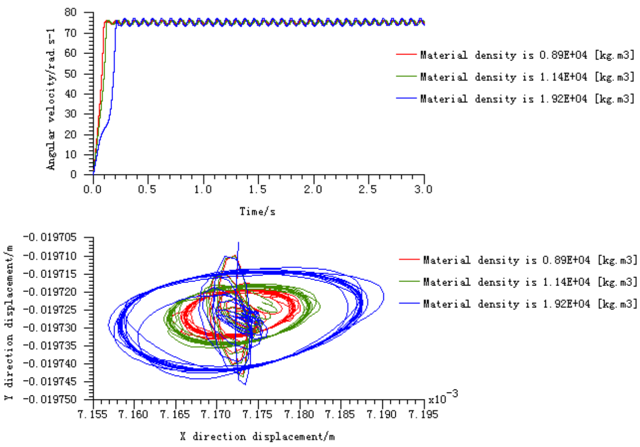

Figure 7. Effect of eccentricity on the quality of the throwing index.

The speed of the three simulation is 900r.min^{-1}, and the material density is 0.89×10^4 kg.m^3, 1.14×10^4kg.m^3, 1.92×10^4kg.m^3. Figure 7 can be seen, with the density (eccentric mass) of the larger, the angular velocity reaches the equilibrium state by the time to grow more, stable time will be longer, the fluctuation range of the vibration is small, and the amplitude of the stability is increased. Three sets of vertical component data are obtained by simulation: 1.64×10^{-5}, 2.24×10^{-5}, 3.61×10^{-5}. Using the formula (5) can be calculated from their throwing index are: 1.26, 1.72, 2.78. Due to the limitation of speed, the three simulation results need to be further improved. According to the requirements of the throwing index, we can see that with the density of the material increases, throwing index also increased, third groups of experimental data is close to the normal work requirements. Therefore, the appropriate choice of materials with large density as the experimental tool can be more close to the ideal experimental results.

5.3. Effect of screen surface inclination

For the different screen surface inclination, due to the change of inclination angle, the center of vibration box is changed and the experimental track diagram's centre is biased. Therefore, the synthetic trajectory of each displacement is listed separately, and the results are shown in Figure 8.

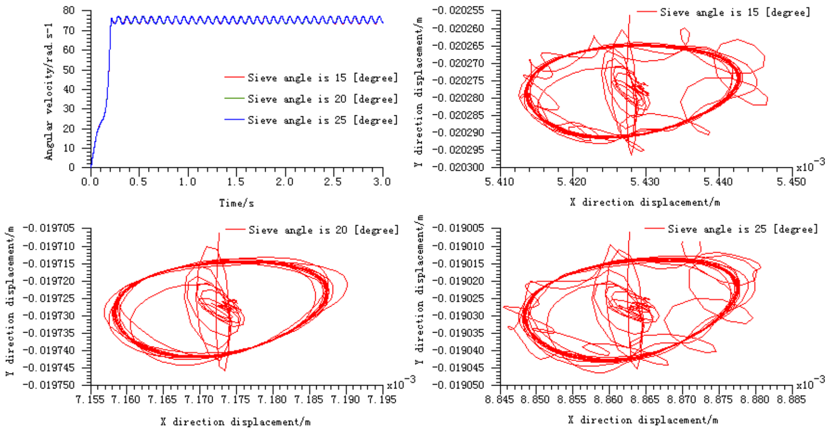

Figure 8. Screen angle effect on the throwing index.

The speed of the three simulation is 900r.min^{-1}, and the screen surface inclination is 15^o, 20^o, 25^o. Can be seen from figure 8, In the three groups, the angular velocity is almost identical, and the same time to achieve stability. It can be obtained that with the change of the angle of the screen surface, there is a great difference in the vibration state before reaching the steady state. In the case of 20^o, the trajectory is relatively concentrated, the vibration amplitude is small, and it is in line with the ideal working state, the vibration of 15^o and 25^o is more dispersed, and it is not practical. Three sets of vertical component data are obtained by simulation: 3.32×10^{-5}, 3.61×10^{-5}, 3.73×10^{-5}. Using the formula (5) can be calculated from their throwing index are: 2.47, 2.78, 2.94. According to the requirements of the throwing index, the latter two groups of test data are more close to the normal range of data. However, when the inclination angle is 25^o, the amplitude of the vibration state is too large to reach a stable state, which can not be included in the reference range, therefore, under normal operating conditions, the inclination angle is more favorable for the 20^o state.

6. Parameter optimization simulation

Through simulation and analysis, motor speed, eccentric quality, screen angle has an effect on the throwing index of vibrating screen, especially in the design, selection of suitable motor speed is necessary. On the basis of above experiments, considering the influence of various parameters on the amplitude stability and throwing index, using Exploration Design module in AMESim to optimize the parameters, set the constraints for the motor speed in the range of 800~1200r.min^{-1}, the material density is maintained at 1.92×10^4 kg.m^3, the screen angle between 15^o~25^o. Through the optimization and simulation of the motor speed, the main effect of the throwing index curve and iteration of the results shown in figure 9, the simulation shows that when the motor speed is 1100 r.min^{-1}, the throwing index is the best. Finally, the material density is 1.92×10^4 kg.m3, the screen surface is 20^o. The simulated image is shown in figure 10.

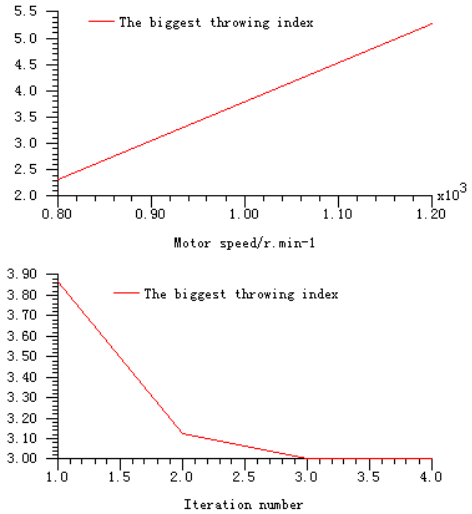

Figure 9. Simulation of motor speed optimization.

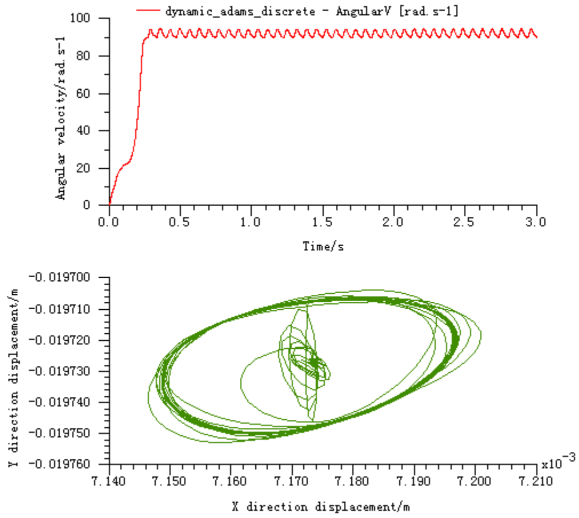

Figure 10. The velocity and displacement of the optimized eccentric angle.

Figure 10 compared with the previous curve, we can see that when the speed is the same, the angular velocity of the eccentric angle is still the same as the stability of the numerical value, and the vibration amplitude is smaller, which is in line with the actual situation before the steady state is reached. The vertical component of the amplitude of the simulation is: 4.39×10^{-5}. Using the formula (5), throwing index calculated is: 3.89. The throwing index is in the range of normal, and in accord with the design requirements of uniaxial shaker. Therefore, it is significant to study the vibration characteristics of vibrating screen by selecting the rotational speed of the motor, the eccentric mass and the dip angle of the screen, also provides reference for the improvement of vibrating screen.

7. Conclusion

In this study, the mathematical model of uniaxial shaker and the combined simulation model of AMESim and ADAMS are established, the vibration characteristics of small vibration sieve are compared and analyzed. Through the simulation results, the following conclusions are drawn:

(1) In uniaxial shaker, the speed of the motor, the quality distribution of the eccentric device, the angle between the screen surface and the ground influence the vibration characteristics of the vibrating screen, meanwhile, they are also an important factor in the ideal working condition of vibrating screen.

(2) The speed of the motor mainly influences the angular velocity of the eccentric device, which directly affects the throwing index size and vibration sieve to achieve stable working efficiency.

(3) The greater the quality of eccentric device, the greater the vibration amplitude of the uniaxial shaker, the time will be extended to reach a stable state. Mainly because of the increase of the eccentric mass, the exciting force will be increased, so that the box is more intense.

(4) Screen angle in the range of vibrating screen is 15^o~25^o, select the appropriate angle, the inclination of 20^o, can make the vibration sieve to vibration state stability before remained stable, with regularity, and step by step to achieve stable operating condition.

In the process of designing and analyzing the vibrating screen, we need to consider all the factors that affect the vibration characteristics of the vibrating screen, and constantly try to get the best result.

Acknowledgments
This work was finically supported by the Foundation of Science and Technology Innovation Talents Team of Guizhou Province ([2014]4013).

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