Modeling and Simulation Analysis on Three-dimensional Excitation Circular Vibrating Screen

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ABSTRACT

The Structure model of three-dimensional excitation circular vibrating screen was established. Then a dynamics analysis based on Lagrange equation was used to analysis this model. MATLAB modeling was utilized to solve centroid differential equations of motion. Centroid movement and other dynamics numerical image of the vibration screen can be obtained by numerical simulation on MATLAB. Simulation analysis shows that the amplitude can be changed by adjusting exciting force of upper and lower eccentric. The path curves of any point in screen surface, as well as material trajectory of screen surface can be modified by adjusting spatial phase angle of upper and lower eccentric. Further alternating vibration effects on amplitude, vibration intensity and other parameters can be obtained through this method. It is a valuable reference to resolving issues of clogging screen mesh and feeding unevenly.

KEYWORDS

Three-dimensional excitation; Circular vibration screen; Lagrange equation; Dynamics; Numerical simulation

INTRODUCTION

Circular vibrating screen is a high precision fine powder sieving equipment. It is suitable for screening filter particles, powder, mucus and other materials. However, plugging screen is a bottleneck [1,2]. In this paper, vertical vibration motor is used as the vibration exciter of circular vibration screen, with eccentric blocks installed at both ends of it. The motor rotary motion can be divided into horizontal, vertical and inclined three-dimensional excitation rotating movement. By adjustment the angle between the two partial blocks, trajectory of the material in the screen surface can be changed [3,4].

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The inertia force and moment of inertia, which is produced by the eccentric blocks of circular screen vibrator, will generate plane whirling vibration of the screen surface. On other hand, this inertia force and moment of inertia also can produce cone rotary vibration of the screen surface. In addition, the angle between upper and lower eccentric blocks along with the effect of gravity make the screen body producing complex rotary type vibration of three-dimensional excitation[5-7]. To explore the solution of the plugging screen in the vibration screen, modeling and simulation analysis on three-dimensional excitation circle vibration screen will been taken and the influence of the changes on the main parameters like the spring stiffness, the eccentric distance of partial block, the angular velocity of exciting motor and etc. will been discussed in the paper [8-10].

**MODEL BUILDING AND FORCE ANALYSIS**

The structure model of the vibration screen is shown in Fig.1. The top view of two partial blocks is shown in Fig.2. The structure simulation model of vibration screen is shown in Fig.3.

In Fig.1, $m$ is the mass of the partial block and two blocks have the same mass. In the top view, the angle between two blocks which are symmetric distribution about the $y$ axis is 600. And $m_0$ is the mass of the vibration system without two partial blocks.

Assuming the system static position is the 0 potential energy position, the right-handed coordinate system of the vibration screen body centroid is built with $O$ origins. If the speed of motor doesn't change, the centrifugal inertia force produced by the exciting motor will be that:

$$ F_1 = F_2 = m r \omega_1^2 $$

Where, $r$ is the radius vector of the partial block’s eccentric mass. $\omega_1$ is angular velocity of the exciting motor and the direction of inertia force is outwards along the
radius vector direction. With the simplification of the inertia force to the screen body centroid, the stress analysis diagram of the centroid could be available in Fig. 4.

\[ F_x = F_{1x} = F_{2x} = 0 \]
\[ F_y = F_{1y} + F_{2y} = \frac{\sqrt{3}}{2} m \omega^2 \times 2 = \sqrt{3} m \omega^2 \]
\[ M_x = \sqrt{3} m \omega^2 h_1 + \frac{\sqrt{3}}{2} m \omega^2 h_2 \]
\[ M_y = -\frac{1}{2} m \omega^2 (h_1 + h_2) + \frac{1}{2} m \omega^2 h_1 = -\frac{1}{2} m \omega^2 h_2 \]

Where, \( h_1 \): the distance from the upper partial block to screen body centroid; \( h_2 \): the distance between the two partial blocks; \( F_x \) and \( F_y \) produce the translational motion of the vibration screen in plane \( xoy \). Meanwhile, \( M_x \) and \( M_y \) produce the flip motion which is the motion of tossing material. From the above, the complicacy motion of the vibration screen is made up of the screening motion in the horizontal plane and the vibration and tossing motion in the vertical plane.

**KINETIC ANALYSIS BASED ON THE LAGRANGE EQUATIONS**

By making the system’s entire mass project onto the plane \( xoy \), the system could be simplified as Fig. 5.

\[ e \] is the eccentric distance of partial block, \( e = \frac{\sqrt{3}}{2} r \). So, the displacement of the system's centroid in three directions is that:
\begin{align}
\begin{cases}
x_c &= x - \frac{2me}{m_0 + 2m} \sin \omega t \\
y'_{c} &= y - \frac{2me}{m_0 + 2m} \cos \omega t \\
z'_{c} &= z
\end{cases} & (1)
\end{align}

The first and the second order derivative of the displacement is that:

\begin{align}
\begin{cases}
\dot{x}_c &= \dot{x} - \frac{2me \omega}{m_0 + 2m} \cos \omega t \\
\dot{y}_c &= \dot{y} + \frac{2me \omega}{m_0 + 2m} \sin \omega t \\
\dot{z}_c &= \dot{z}
\end{cases} & (2)
\end{align}

\begin{align}
\begin{cases}
\ddot{x}_c &= \ddot{x} + \frac{2me \omega^2}{m_0 + 2m} \sin \omega t \\
\ddot{y}_c &= \ddot{y} + \frac{2me \omega^2}{m_0 + 2m} \cos \omega t \\
\ddot{z}_c &= \ddot{z}
\end{cases} & (3)
\end{align}

If the flip angular velocity of the screen body in the vibration process is a constant value \( \omega_2 \) and the rotational inertia of the screen body is a constant value \( I_{xy} \), the kinetic energy of the system would be that:

\[ T = \frac{1}{2} J_{xy} \omega^2 + \frac{1}{2} (m_0 + 2m)(\dot{x}_c^2 + \dot{y}_c^2 + \dot{z}_c^2) \]  

(4)

If the changes of four main vibration springs' length are the same, the potential energy of the system will be that:

\[ V = 4 \times \frac{1}{2} \left[ k_{xy} (x_c^2 + y_c^2) + k_z z_c^2 \right] + (m_0 + 2m)gz_c \]

\[ = 2k_{xy} (x_c^2 + y_c^2) + 2k_z z_c^2 + (m_0 + 2m)gz_c \]  

(5)

Where, \( k_{xy} \) is the spring stiffness in \( xoy \) plane; \( k_z \) is the spring stiffness in the \( z \) axial direction.

Substitution Eq.4 and Eq.5 to Lagrange function, then

\[ L = T - V \]

\[ = \frac{1}{2} J_{xy} \omega^2 + \frac{1}{2} (m_0 + 2m)(\dot{x}_c^2 + \dot{y}_c^2 + \dot{z}_c^2) - 2k_{xy} (x_c^2 + y_c^2) \]

\[ - 2k_z z_c^2 - (m_0 + 2m)gz \]

According to \( \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{x}_c} \right) - \frac{\partial L}{\partial x_c} = 0 \), we get

\[ (m_0 + 2m)\ddot{x} + 4k_{xy} x = \left( \frac{8k_{xy} me}{m_0 + 2m} - 2me \omega^2 \right) \sin \omega t \]
Similarly, we get

\[ \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{y}_c} \right) - \frac{\partial L}{\partial y_c} = 0 \]

we get

\[ (m_0 + 2m)\ddot{y} + 4k_{sy}y = \left( \frac{8k_{me}}{m_0 + 2m} - 2me\omega_1^2 \right) \cos \omega_1 t \]

And

\[ \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{z}_c} \right) - \frac{\partial L}{\partial z_c} = 0 \]

we get

\[ (m_0 + 2m)\ddot{z} + 4k_{sz}z + (m_0 + 2m)g = 0 \]

we also get

\[ J_{sy}\ddot{v} = 0 \]

Where, \( v \) is flip angle of screen body, and \( \dot{v} = \omega_2 \). Finally, we get

\[
\begin{align*}
(m_0 + 2m)\ddot{x} + 4k_{sx}x &= \left( \frac{8k_{me}}{m_0 + 2m} - 2me\omega_1^2 \right) \sin \omega_1 t \\
(m_0 + 2m)\ddot{y} + 4k_{sy}y &= \left( \frac{8k_{me}}{m_0 + 2m} - 2me\omega_1^2 \right) \cos \omega_1 t \\
(m_0 + 2m)\ddot{z} + 4k_{sz}z + (m_0 + 2m)g &= 0 \\
J_{sy}\ddot{v} &= 0
\end{align*}
\]

And

\[ (m_0 + 2m)\ddot{y} + 4k_{sy}y = \left( \frac{8k_{me}}{m_0 + 2m} - 2me\omega_1^2 \right) \cos \omega_1 t \]

By solving the differential equation, the motion equation of the vibration screen body centroid could be obtained, and then the numerical simulation of the vibration process could be gotten based on Matlab. Further, vibration intensity and many other parameters could also be available.

**NUMERICAL SIMULATION AND ANALYSIS**

In the simulation, \( m_1 = 20 \text{kg} \), \( m = 1.5 \text{kg} \). By using the Matlab, the solution of the differential equation could be available.

\[
\begin{align*}
x &= -\frac{3e\sqrt{k_{sy}}[\sqrt{5}\omega_1 \sin(\frac{t}{\sqrt{5}}) - \sqrt{5}\omega_1 \sin(\omega_1 t)]}{20} \\
y &= -\frac{3e[\cos(\frac{t}{\sqrt{5}}) - \cos(\omega_1 t)]}{\sqrt{5}} \\
z &= \frac{50[2\cos(\frac{\sqrt{5}}{5}\sqrt{k_{sy}t}) - 1]}{k_z}
\end{align*}
\]

From the equation above, the main movement of the screen body in plane \(xo'y'\) is related to the stiffness \( k_{sy} \) of the main vibration spring in the plane \( xo'y' \), the eccentric distance \( e \) of partial block and the angular velocity \( \omega_1 \) of the vibration exciter motor. The vibration in the \( z \) direction of the system is related to the stiffness \( k_z \) of the main vibration spring in the \( z \) direction.

According to the equations above, numerical analysis of the system is that:

1) In the case of other conditions unchanged, if just the stiffness \( k_{sy} \) of the main vibration spring in the plane \( xo'y' \) was changed, the displacement of screen body could be seen in Fig.6.
(a) In x axial direction (b) In y axial direction

Figure 6. The displacement diagram of screen body when $k_{xy}$ changed.

As we can see from above, the displacement in the $x$ direction decreases with the increase of the $k_{xy}$, but the displacement in the $y$ direction is limited. So, the value of $k_{xy}$ should be selected by the design of the main vibration spring and its value shouldn't be too large. According to the design of the main vibration spring, the equivalent stiffness in the direction of $xoy$ should be $k_{xy} = 60 N/mm$.

2) In the case of other conditions unchanged, if just eccentric distance $e$ was changed, the displacement of screen body could be seen in Fig.7.

So, the displacements in the direction $x$ and direction $y$ are both increasing with the increase of $e$. Because of the limit of the system's structure, $e$ shouldn't be too large. The increase of $e$ has not much effect on vibration intensity. Therefore, $e = \frac{\sqrt{3}}{2} \times 35 = 30.3 mm$.

3) In the case of other conditions unchanged, if just the angular velocity $\omega_1$ of the vibration exciter motor was changed, the displacement of screen body could be seen in Fig.8.

It's clear that the displacement in direction $x$ is gradually increasing with the increase of $\omega_1$. While the displacement in direction $y$ changes a little.
According to the equation, \[ k = \frac{\omega_t^2 \lambda}{g} \]

Where, \( \lambda \) is the amplitude.

When \( k \geq 10 \), the system becomes a high vibration intensity system. So \( \omega_t \) should be as large as possible. According to the real parameters of the vibration exciter motor, the motor is selected to be the one with the revolving speed \( n_0 = 1460 \text{ r/min} \). The angular velocity is:

\[ \omega_t = \frac{2\pi n_0}{60} = 152.9 \text{ rad/s} \]

4) The relation between the displacement in direction \( z \) and the stiffness \( k_z \) of the main vibration spring in \( z \) direction is shown in Fig.9.

The displacement in direction \( z \) decreases with the increase of \( k_z \). According to the equation of the value \( k \) in vibration system, vibration intensity \( k \) is increasing with the increase of amplitude. The bigger the vibration intensity \( k \) is, the easier the high vibration intensity is achieved. So when the main vibration spring is designed, the value of \( k_z \) should be 35N/mm and \( \lambda \) is about 5.8 to satisfying application condition. These dates above are close to the real condition of the vibration screen. Taking the data into the equation of the vibration intensity, it would be that:

\[ k = \frac{\omega_t^2 \lambda_z}{g} = \frac{152.9^2 \times 5.8}{9.8} = 13.8 > 10 \]

All of the numerical simulation, we can get the vibration trajectory of arbitrary point in screen surface is a complicated space curve. The curve can be a circle in the horizontal plane projection, while the projection on the vertical surface can be an oval.
Amplitude can be changed by adjusting exciting force of upper and lower eccentric blocks. Material motion trajectory of screen surface can be changed by adjusting spatial phase angle between upper and lower eccentric blocks. Further amplitude, vibration intensity, vibration frequencies and other main vibration parameters can be changed by adjusting the angular velocity of the vibration motor, the spring stiffness or other related parameters. Multilayer vibrating sieve will work under higher vibration intensity through this adjustment. Then the system will even get changeable amplitude and frequency. The adjustment of parameters is for the purpose of increasing the sieve permeation rate and reducing stuck and agglomeration, which is the main issue this numerical simulation focus on.

CONCLUSIONS

1) Three-dimensional excitation circular vibrating screen was constructed. The centroid motion equation of vibrating screen was solved based on Lagrange equation and MATLAB software. The kinematics and dynamics numerical images of vibrating screen were obtained by numerical simulation. All of these are basis of the study on the vibration state of vibrating screen.

2) Analysis of the image above shows amplitude can be changed by adjusting exciting force of the upper and lower eccentric blocks. Material motion trajectory of screen surface also can be changed by regulating spatial phase angle of the upper and the lower eccentric blocks. The vibrating screen will have alternating amplitude and varied vibration intensity through the adjustment above. The simulation analysis provides a valuable reference to resolving the existing issues of screen mesh clogging.

ACKNOWLEDGMENT

The authors acknowledge the financial support from National Natural Science Foundation of China (Grant No. 51375221), Key Scientific and technological projects of Henan (142102210138) and Scientific and technological projects of Zhengzhou City (20130797) as well as by college students of science and technology innovation projects in Jiangsu Province (201511276005Z).

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