Dynamic analysis of a chaotic vibrating screen

Song Yan*, Jiang Xiao-hong, Song Juan, Zhang Jian-xun

China University of Mining & Technology, Xuzhou 221116, China

Abstract

A new type of multi-degree-of-freedom and highly efficient vibrating screen based on multi-degree of freedom mechanics principle of dynamics is presented. Its prominent character is to have an additionally high frequency and short amplitude vibration on long amplitude vibration. And it can efficiently increase probability of material crashing, eliminate blinding aperture, and get high screening efficiency. A series of mechanics Equ.s are set up and parameter vibrating wave charts are gained by emulator of Matlab.

Keywords: vibrating screen; dynamic analysis; screening efficiency; chaos

1. Introduction

The precisely screening process of coal is an effective way to improve the quality and structure of coal production and to increase economic efficiency and social energy saving benefit. At present, the key problem of restraining the precisely screening process of moist raw coal is the small size of particles, big specific surface area, and blinding aperture caused by water. It is difficult for ordinary vibrating screen to complete this screening task. Existing wet screening machines make it difficult to use fine-coal dry screening to screen the wet raw coal. Therefore, in recent years for the mechanical engineering and mineral process engineering, the focus is on the research into processing the difficult screening materials. As the screening machine is very easy to be blinded when screening, this topic has been extensively and deeply studied both at home and abroad. In this paper, we intend to develop a new type of multi-degree-of-freedom chaotic vibrating screen.

2. Structure and working principle of chaotic vibrating screen

Figure 1 is the structure of a chaotic vibrating screen. Vibrator is constituted of components 1, 2, 3, 4, and 5. Long bars 1 and 3 cause acceleration vibration of long period, short bars 2 and 4 cause acceleration vibration of short period, the superposition of the two vibrations make the material loose and get a high screening efficiency. In order to make the material screen easier, the box of screen should be tilted for a large angle (about 30°) for viscous material. The vibrating screen, component 1 is an initiative component. Driving torque, components, box of the screen and material form a dynamic system. When the motor drives the power system into motion, box of the...
screen will have a chaotic motion. This motion will effectively promote screening efficiency if incentive frequency and bars are designed suitably.

Fig. 1. Diagram of dynamics of the chaotic vibrating screen

The degree of freedom of the chaotic vibration shown in Fig. 1 is \( F = 3 \times 5 - (2 \times 6 + 0) = 3 \). According to the definition of classic institutions, the necessary and sufficient condition of the specified movement is that the number of the original is equal to the number of the degree of motion. If the number of freedom of motion is greater than the number of the original, we cannot call it mechanism. However, with the development of the mechanism dynamics, the concept of mechanism has become extended. If we think about the space of kinematic pair or elasticity of components when analyzing dynamic of components, the number of the freedom of motion is far greater than the number of the original components’, then the mechanism is dynamic mechanism. When the number of original components is less than the number freedom of motion, the location of the follower is the function of the mass of the mechanism, moment of inertia, and external force. When the size is suitably selected, the output movement of the mechanism may be the compound movement of long period vibration followed with short period vibration. This mechanism has three freedom degrees of motion, one generates long amplitude vibration on screen mesh, the other two create high frequency and chaotic vibration. At present, chaotic phenomenon is considered to be one of the most complex motions in dynamic system, which includes all kinds of dynamic system. Chaos is a nonlinear dynamic behavior, which generate fixed point and periodic point, and reach specific form of "disorder" through multiplicative process. As for nonlinear dynamics, people used to make the linear model to approach to true system, simplify dynamic analysis and design. However, this linear approximation is not always feasible, the nonlinear factors which are overlooked often cause unacceptable error in analysis and calculation. In recent years, people realized that, if they want to design and produce high-quality system, they must command the nonlinear dynamic behavior of the system.

Vibrating screens depend on the vibrating of the screen mesh making materials to throw, collide, separate, and roll or slid so that it can implement screen through relative collision between materials and screen mesh. To have an additionally long period vibration on short period vibration can increase the probability of collision between materials and materials and between materials and screen meshes, then the materials can be easily decentralized and screened. This new chaotic vibrating screen can achieve the purpose of screening efficiency.

3. Dynamic analysis of chaotic vibrating screen

In building coordinate system of every component shown in figure 1, given that the length of crack 1 is \( l_1 \), angular velocity is \( \delta_1 \), rotational inertia about point \( A_1 \) is \( J_{A_1} \), the length of connecting bar is \( l_2 \), angular displacement is \( \delta_2 \), rotational inertia about point \( C \) is \( J_C \); the lengths of short bars 2 and 4 are \( e_1 \) and \( e_2 \), angular displacement is \( \tau_1 \) and \( \tau_2 \), rotational inertia of short bar 4 about point \( D \) is \( J_D \), horizontal and vertical distance between point \( E \) on the screen box and the origin of the coordinate is \( x_5 \) and \( y_5 \).

3.1. Motion equations of crack
From figure 2, we can get the rotational differential equation of the crack:

\[ J_\alpha \cdot \ddot{\delta}_1 = -F_{21x} \cdot l_1 \sin \delta_1 + F_{21y} \cdot l_1 \cos \delta_1 + M_\delta (\omega_1) \]  \( (1) \)

Fig. 2. Stress analysis model of the crack

3.2. Motion equations of the first eccentric shaft

From figure 3, we can get differential equations of the first eccentric shaft:

\[ J_B \cdot \ddot{\tau}_1 = -F_{32x} \cdot e_1 \sin \tau_1 + F_{32y} \cdot e_1 \cos \tau_1 \]  \( (2) \)

\[ m_2 \ddot{x}_2 = F_{32x} - F_{12x} \]  \( (3) \)

\[ m_2 \ddot{y}_2 = -F_{12y} + F_{32y} - m_2 \cdot g \]  \( (4) \)

3.3. Motion equations of the guide bar

From figure 4, we can get differential equations of the connecting bar:

\[ J_c \ddot{\delta}_2 = -0.5m_3 \cdot g \cdot l_2 \cdot \cos \delta_2 + F_{43x} \cdot l_2 \sin \delta_2 + F_{43y} \cdot l_2 \cos \delta_2 \]  \( (5) \)

\[ m_3 \ddot{x}_3 = F_{43x} - F_{23x} \]  \( (6) \)

\[ m_3 \ddot{y}_3 = F_{43y} - F_{23y} - m_3 g \]  \( (7) \)

Fig. 4. Stress analysis model of the connecting bar

Fig. 5. Stress analysis model of the second eccentric shaft
3.4. Motion equations of the second eccentric shaft

From figure 5, we can get the differential equations of the second eccentric shaft:

\[ J_D \ddot{x}_2 = F_{54x} \cdot e_2 \sin \tau_2 + F_{54y} \cdot e_2 \cos \tau_2 \]  
\[ m_4 \ddot{x}_4 = F_{54x} - F_{34x} \]  
\[ m_4 \ddot{y}_4 = F_{54y} - F_{34y} - m_4 g \]  

3.5. Motion equations of the box

\[ m_5 \ddot{x}_5 = F_{N} \cdot \sin \alpha - F_{45x} \]  
\[ m_5 \ddot{y}_5 = F_{45y} - F_{N} \cdot \cos \alpha - m_5 g \]  

From constrain conditions, we can get vector closed equations of the mechanism:

\[ l e^{i \delta_1} + e_4 e^{i \delta_1} = -y_4 \cdot e^{-i \tau_1} + x_4 \cdot e^{i \delta_1} + e_2 e^{i \theta_2} + l_2 e^{i \delta_2} \]  
\[ x_2 = l_1 \cdot \cos \delta_1 \]  
\[ y_2 = l_1 \cdot \sin \delta_1 \]  
\[ x_3 = l_1 \cdot \cos \delta_1 + e_1 \cdot \cos \tau_1 \]  
\[ y_3 = l_1 \cdot \sin \delta_1 + e_1 \cdot \sin \tau_1 \]  
\[ x_4 = l_1 \cdot \cos \delta_1 + e_1 \cdot \cos \tau_1 - l_2 \cdot \cos \delta_2 \]  
\[ y_4 = l_1 \cdot \sin \delta_1 + e_1 \cdot \sin \tau_1 - l_2 \cdot \sin \delta_2 \]  

The first derivative on time of every variable is got from Equ. (14) to Equ. (19)

\[ \dot{x}_2 = -l_1 \cdot \dot{\delta}_1 \sin \delta_1 \]  
\[ \dot{y}_2 = l_1 \cdot \dot{\delta}_1 \cos \delta_1 \]  
\[ \dot{x}_3 = -l_1 \cdot \dot{\delta}_1 \sin \delta_1 - e_1 \cdot \dot{\tau}_1 \sin \tau_1 \]  
\[ \dot{y}_3 = l_1 \cdot \dot{\delta}_1 \cos \delta_1 + e_1 \cdot \dot{\tau}_1 \cos \tau_1 \]
\[ \ddot{x}_4 = -l_1 \ddot{\delta}_1 \sin \delta_1 - e_1 \cdot \dot{r}_1 \sin \tau_1 + l_2 \cdot \ddot{\delta}_2 \sin \delta_2 \]
\[ \ddot{y}_4 = l_1 \ddot{\delta}_1 \cos \delta_1 + e_1 \cdot \dot{r}_1 \cos \tau_1 - l_2 \cdot \ddot{\delta}_2 \cos \delta_2 \]

The second derivative on time of every variable is got from Equ. (20) to Equ. (25)

\[ \ddot{x}_2 = -l_1 \ddot{\delta}_1 \cos \delta_1 - l_1 \ddot{\delta}_1 \sin \delta_1 \]
\[ \ddot{y}_2 = -l_1 \ddot{\delta}_1 \sin \delta_1 + l_1 \ddot{\delta}_1 \cos \delta_1 \]
\[ \ddot{x}_3 = -l_1 \ddot{\delta}_1 \cos \delta_1 - l_1 \ddot{\delta}_1 \sin \delta_1 - e_1 \cdot \dot{r}_1^2 \cos \tau_1 - e_1 \cdot \dot{r}_1 \sin \tau_1 \]
\[ \ddot{y}_3 = -l_1 \ddot{\delta}_1 \sin \delta_1 + l_1 \ddot{\delta}_1 \cos \delta_1 - e_1 \cdot \dot{r}_1^2 \sin \tau_1 + e_1 \cdot \dot{r}_1 \cos \tau_1 \]
\[ \ddot{x}_4 = -l_1 \ddot{\delta}_1 \cos \delta_1 - l_1 \ddot{\delta}_1 \sin \delta_1 - e_1 \cdot \dot{r}_1^2 \cos \tau_1 + e_1 \cdot \dot{r}_1 \cos \tau_1 + l_2 \cdot \ddot{\delta}_2 \cos \delta_2 + l_2 \cdot \ddot{\delta}_2 \sin \delta_2 \]
\[ \ddot{y}_4 = -l_1 \ddot{\delta}_1 \sin \delta_1 + l_1 \ddot{\delta}_1 \cos \delta_1 - e_1 \cdot \dot{r}_1^2 \sin \tau_1 + e_1 \cdot \dot{r}_1 \cos \tau_1 + l_2 \cdot \ddot{\delta}_2 \sin \delta_2 \]

Expend Equ. (13) according to Euler’s formula

\[ l_1 e^{i \delta_1} + e_1 e^{i \tau_1} = -y_3 \cdot e^{-i \delta_1/2} + x_1 \cdot e^{i \delta_1} + e_2 e^{i \dot{\delta}_1} + l_2 e^{i \dot{\delta}_2} \]
\[ l_1 \cdot \cos \delta_1 + e_1 \cdot \cos \tau_1 = x_1 + e_2 \cdot \cos \tau_2 + l_2 \cdot \cos \delta_2 \]
\[ -y_3 + l_1 \cdot \sin \delta_1 + e_1 \cdot \sin \tau_1 = e_2 \cdot \sin \tau_2 + l_2 \cdot \sin \delta_2 \]

The first and the second derivatives with respect to time are got respectively in Equ. (32) and Equ. (33)

\[ -l_1 \ddot{\delta}_1 \sin \delta_1 - e_1 \cdot \dot{r}_1 \sin \tau_1 = \ddot{x}_4 - e_2 \cdot \dot{r}_2 \sin \tau_2 - l_2 \cdot \ddot{\delta}_2 \sin \delta_2 \]
\[ -\ddot{y}_3 + l_1 \ddot{\delta}_1 \cos \delta_1 + e_1 \cdot \dot{r}_1 \cos \tau_1 = e_2 \cdot \dot{r}_2 \cos \tau_2 + l_2 \cdot \ddot{\delta}_2 \cos \delta_2 \]
\[ -l_1 \ddot{\delta}_1 \cos \delta_1 - l_1 \ddot{\delta}_1 \sin \delta_1 - e_1 \cdot \dot{r}_1^2 \cos \tau_1 - e_1 \cdot \dot{r}_1 \sin \tau_1 = \]
\[ \ddot{x}_5 = e_2 \cdot \dot{r}_2^2 \cos \tau_2 - e_2 \cdot \dot{r}_2 \sin \tau_2 - l_2 \cdot \ddot{\delta}_2 \cos \delta_2 - l_2 \cdot \ddot{\delta}_2 \sin \delta_2 \]
\[ -\ddot{y}_5 - l_1 \cdot \dot{r}_1 \sin \tau_1 = e_1 \cdot \dot{r}_1 \sin \tau_1 + e_1 \cdot \dot{r}_1 \cos \tau_1 = \]
\[ -e_2 \cdot \dot{r}_2 \sin \tau_2 + e_2 \cdot \dot{r}_2 \cos \tau_2 - l_2 \cdot \ddot{\delta}_2 \cos \delta_2 + l_2 \cdot \ddot{\delta}_2 \cos \delta_2 \]

The acceleration of the screen box moving diagonally satisfy

\[ \ddot{y}_5 = \ddot{x}_5 \cdot \tan \alpha \]
4. Simulating curves and analysis

According to the above formulas, using MATLAB to program, simulating the movement trajectory, we can get curves, and choose some of them for further analysis.

According to figures 7, 8, 9, and 10, the horizontal direction (x) represent time, the vertical direction (y) represent displacement. In order to test the correctness of the solutions based on dynamics method, we suppose that the length of short bars be \( e_1 = e_2 = 0 \text{mm} \). Given that the rotational speed is a constant in this situation, as shown in figure 7, the movement curve of the screen box is single and long amplitude reciprocating motion. Its movement trajectory is fixed and there is no chaotic phenomena, indicating that the result obtained from dynamic method is similar to the result obtained from kinetic method. Therefore, both the dynamic equations and simulation through MATLAB are accurate.

As shown in figure 8, when the length of the bars is \( e_1 = e_2 = 1 \text{mm} \), the character of the high harmonic movement can be seen but not obvious; for screening viscous material, the probability of crashing among materials is small. As shown in figure 9, when the length of the bars is \( e_1 = e_2 = 3 \text{mm} \), the character of the high harmonic movement is obvious, the original character of the periodic movement isn’t damaged, and the chaotic movement is obvious. Therefore, the character of the highly harmonic movement can increase the rate of the crashing and make the materials easy to be dispersed. For increasing viscous materials, an obvious effort should be made to improve the viscosity and blinding. As shown in figure 9, when the length of the bars is \( e_1 = e_2 = 6 \text{mm} \), the character of the high harmonic movement is very obvious, but the frequency and the amplitude begin to reduce. The balance of the movement is destroyed, it no longer has the positive effort to improve the viscosity and blind.

5. Conclusion

A new type of multi-degree-of-freedom and high efficient vibrating screen based on multi-degree of freedom is presented, which makes use of long amplitude vibrating superimposing high frequency and short amplitude vibration. In theory, it can efficiently increase probability of crashing among materials or between materials and screen mesh, scatter viscous materials, and separate materials from screen mesh. Therefore, it will effectively avoid bonding between materials and eliminate blinding aperture. According to movement curves got from MATLAB, it is possible to get a high frequency and short amplitude vibration on the basis of long amplitude as long as the length of bars is suitably chosen so as to achieve better screening effect for viscous material.
References

[1] C. Liu, Design and experimental research of screening machine of two degrees of freedom. Journal of Coal. 3 (2004) 364-366.

[2] C. Liu, Dynamic characteristics of the flip screen and researches of its process parameters. China University of Mining Journal. 29 (2000) 290-292.

[3] Y. Zhao and C. Liu, Theory and application of dry screening. The Science Press, 1999.