877. Design and performance analysis of dual vibrating motors self synchronous shaker with balanced elliptical motion

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Abstract. According to the basic principle of machine dynamics, the mechanical model of the dual vibrating motors self synchronous shaker with balanced elliptical motion is established. By virtual prototype technology, the kinematic and dynamic characteristic simulation analysis of the sieving box was carried out. The motion path, natural frequencies and mode shapes of the sieving box were calculated, the stress and deformation distribution in every part of the sieving box under rate load were obtained, and the dynamic strength analysis of the sieving box was carried out. The results show that, the structure design of the shaker is reasonable, and its dynamic strength is satisfied.

Keywords: balanced elliptical motion shaker, vibrating motor, virtual prototype technology, dynamic behavior, finite element analysis.

1. Introduction

A drilling fluid shale shaker is a vibrator used for solid/liquid separation. It is an important device in the solids-control system because efficient operation of other surface solids separation equipment is critically dependent on proper functioning of the shaker. The purpose of using a shaker is to recover drilling fluid and remove large solids as most as possible. A well designed shale shaker will not only maximize use of the screen cloth to separate solids from liquid, but will also convey these solids off the screen quickly, minimizing fluid loss with the solids and clearing the screen for more feed. With the rapid development of drilling new technology, the requirement for drilling fluid solids control is getting higher and higher. The research for solids control equipments especially for the shaker is paid closer attention by world drilling engineers. Much researching work on vibration principle, vibration pattern, kinematics, dynamics and vibration measurement of a shaker has been done [1-12]. A balanced elliptical motion shale shaker is a new type of vibrating screen having advantages of the circular shaker and the linear shale shaker [13]. Using gear drive force synchronous mode on the two excitation axes, Zhang [14] has realized balanced elliptical motion, but this type of shale shaker has disadvantages of vibrating noise, complex structure, inconvenient bearing lubrication and maintenance. Hou and Ren [15-16] used dual vibrating electric motors self synchronous principle to realize balanced elliptical motion. Dual vibrating electric motors self synchronous shale shaker with balanced elliptical motion has the advantage of simpler structure, lower noise, and easier maintenance than the gear drive forced synchronous shaker with balanced elliptical motion, and has larger processing capacity than the self synchronous linear shaker, so this type of shale shaker will have a wide application in the future. In this article, according to the self synchronous theory with two vibrating electric motors, a balanced elliptical motion shale shaker is designed. Based on virtual prototype technology, the kinematic and dynamic characteristic simulation analysis of the sieving box was carried out. All these can provide a basis for design improvement and experiment research of dynamic strength of the shale shaker.

2. Dynamic Model of the Shaker

In general, a drilling fluid shale shaker is composed of vibration exciter, sieving box and supporting devices. In the dual vibrating electric motors self synchronous shaker with balanced elliptical motion, the two vibrating electric motors are installed on the sieving box directly. Two eccentric blocks with different mass moment are installed on each vibrating axis. When the axes rotate, they can produce inertia force. When the force center of the vibrating forces coincides with the quality center of the vibrating quality, the balanced elliptical motion of the sieving box will be realized. The vibrating shaker is a complicated space multi-freedom degree system, in order to simplify, we neglect the unimportant pitching vibration, treat the sieving box as a linear vibration problem of a rigid beam in a longitudinal symmetrical plane [17, 18].

The masses of the sieving and the eccentric blocks are M, m_1, m_2, respectively. Mass moments of the eccentric blocks are $m_1 r_1$, $m_2 r_2$, respectively. The circular frequency of the vibrating axes is ω. Take the quality center of the vibrating quality as the origin of coordinates, establish coordinated system as shown in Fig. 1. Suppose, the phase angle difference between the two eccentric blocks is $\Delta\alpha$, so, $\phi_1 = \omega t + \frac{\Delta\alpha}{2}$, $\phi_2 = \omega t - \frac{\Delta\alpha}{2}$.

The inertia forces of the two eccentric blocks resolve in x, y directions:

$$F_x = (F_1 - F_2)\cos\frac{\Delta\alpha}{2}\cos\omega t - (F_1 + F_2)\sin\frac{\Delta\alpha}{2}\sin\omega t, \quad (1)$$

$$F_y = (F_1 + F_2)\cos\frac{\Delta\alpha}{2}\sin\omega t + (F_1 - F_2)\sin\frac{\Delta\alpha}{2}\cos\omega t, \quad (2)$$

where r_1, r_2 are the distances between the quality center of the eccentric block and its rotating center, respectively. ϕ_1, ϕ_2 are the phase angles of the eccentric blocks, respectively. $F_1 = m_1 r_1 \omega^2$, $F_2 = m_2 r_2 \omega^2$.

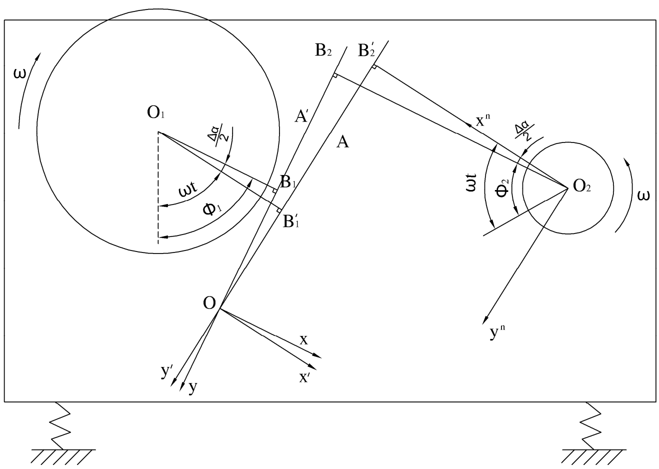

Fig. 1. Mechanical model of the shaker

Vibrating equations for the vibrating box are:

$$M\ddot{X} + C_x\dot{X} + K_xX = F_x, \quad (3)$$

$$M\ddot{Y} + C_y\dot{Y} + K_yY = F_y, \quad (4)$$

where C_x, C_y are damp coefficient components in x, y directions, respectively. K_x, K_y are stiffness coefficient components of the spring in x, y directions, respectively. X, $\dot{X}$, $\ddot{X}$ are displacement, velocity and acceleration components of the sieving box in x direction, respectively. Y, $\dot{Y}$, $\ddot{Y}$ are displacement, velocity and acceleration components of the sieving box in y direction, respectively.

Because a drilling fluid shale shaker is an inertia vibrating screen, so we can neglect the damped forces and the elastic forces [19]. Simplify Eq. 3 and Eq. 4:

$$M\ddot{X} = F_x , \tag{5}$$

$$M\ddot{Y} = F_y . \tag{6}$$

When the sieving box works in a stable state, the particular solution of Eq. 5 and Eq. 6:

$$X = \frac{(F_1 - F_2)\cos\frac{\Delta\alpha}{2}}{-M\omega^2}\cos\omega t - \frac{(F_1 + F_2)\sin\frac{\Delta\alpha}{2}}{-M\omega^2}\sin\omega t , \tag{7}$$

$$Y = \frac{(F_1 + F_2)\cos\frac{\Delta\alpha}{2}}{-M\omega^2}\sin\omega t + \frac{(F_1 - F_2)\sin\frac{\Delta\alpha}{2}}{-M\omega^2}\cos\omega t . \tag{8}$$

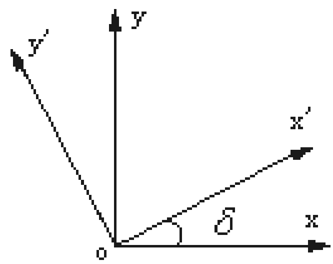

Fig. 2. Coordinate transformation

Take a coordinate transformation, as shown in Fig. 2, $\delta = \Delta\alpha / 2$, so:

$$X = X'\cos\delta - Y'\sin\delta , \tag{9}$$

$$Y = X'\sin\delta + Y'\cos\delta . \tag{10}$$

Substitute Eq. 9 and Eq. 10 into Eq. 7 and Eq. 8:

$$X' = \frac{F_1 - F_2}{-M\omega^2}\cos\omega t , \tag{11}$$

$$Y' = \frac{F_1 + F_2}{-M\omega^2}\sin\omega t . \tag{12}$$

So:

$$\frac{X'^2}{\left(\frac{m_1 r_1 - m_2 r_2}{M}\right)^2} + \frac{Y'^2}{\left(\frac{m_1 r_1 + m_2 r_2}{M}\right)^2} = 1 . \tag{13}$$

Eq. 13 is an elliptical equation. That is, the motion trace of the sieving box is ellipse, the length of its major axis is $(m_1 r_1 + m_2 r_2) / M$, the length of its minor axis is $(m_1 r_1 - m_2 r_2) / M$. $(F_1 - F_2)/(F_1 + F_2)$ decides the magnitude of ellipticity.

3. Kinematic Behavior Analysis of the Sieving Box

3.1 Kinematic Model of the Sieving Box

The sieving box is a space assembled structure with five boards and sixteen reinforced beams. In order to strengthen rigidity, the side boards and supporting plates of the electric motors are reinforced with edge boards. The whole sieving box is supported by four columniform spiral springs. Construct three-dimensional model of each part and assemble them in CATIA software. By means of graphic interface of ADAMS/View, put the simplyfied assembled model into ADAMS software, so we can analyse the kinetic characteristic of the sieving box. The kinematic simulation model of the sieving box is shown in Fig. 3.

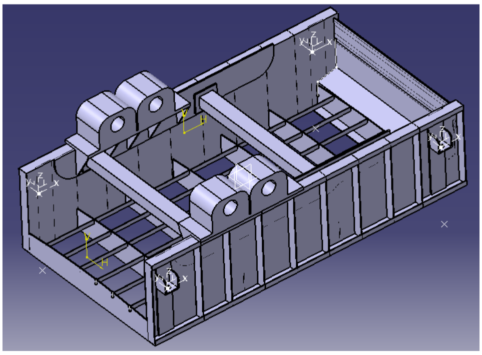

Fig. 3. Kinematic simulation model of the sieving box

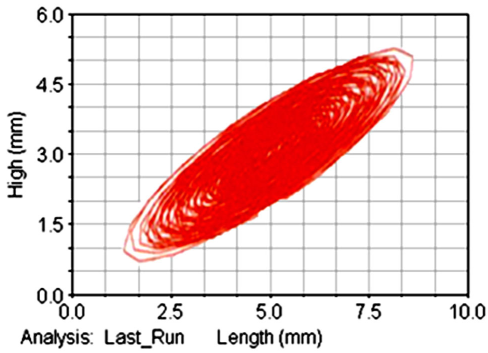

Fig. 4. Motion path of the sieving box

3.2 Mechanical Model of the Damping Spring

The mechanical model building of the damping spring is very important, because the arrangement and parameter selection of damping spring will have a direct impact on the simulation model of the sieving box. Supposes the damping of the spring is viscous-damping [20], so the mechanical model of the damping spring is:

$$F = -C(dR/dt) - K(R - R_0) + F_0, \tag{14}$$

where R is the relative displacement of the spring at both ends, dR/dt is the relative velocity of the spring at both ends, C is viscous damping coefficient, K is stiffness coefficient of the spring, R_0 is the initial relative displacement of the spring at both ends, F_0 is pre-load of the spring.

3.3 Kinematic Simulation of the Sieving Box

Add constraints, initializing motion, elastic forces and vibrating forces, so we can analyse the kinetic characteristic of the sieving box in ADAMS software. Motion trace of the sieving box is shown in Fig. 4.

4. Dynamic Behavior Analysis of the Sieving Box

The drilling fluid shale shaker is screening machinery which works using vibration principle. But if the excitation frequency is equal to its natural frequency, the shaker will work in resonance region, then, this will not only affect normal working of the shaker, and also make the shaker premature destruction. The dynamic characteristics of drilling fluid shale shaker include inherent characteristics and dynamic response, the dynamic response is synthesis performance of inherent characteristic and excitation forces.

4.1 Finite Element Model of the Sieving Box

The sieving box is a comparative regular assembled structure with boards and beams. In order to not lose modal characteristic, take the whole sieving box as an analytical example. Substitute such connecting parts as bolts, hold-down plates, etc. with concentrated masses. Substitute the vibrating electric motors with two concentrated masses. The supporting springs are simplied as tension-compression boundary elements. The finite element model for the sieving box is shown in Fig. 5, having 3346 nodes, 9520 elements, four boundary elements and three mass elements [21].

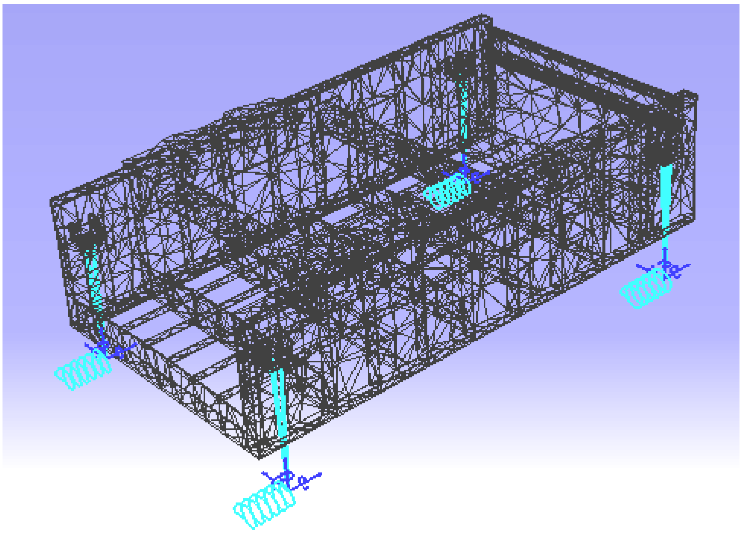

Fig. 5. Finite element model of the sieving box

4.2 Modal Analysis of the Sieving Box

Applying the structure analysis module of CATIA software, we can get the characteristic of oscillation mode and frequencies of the sieving box, as shown in Table 1.

Table 1. Modal characteristic of the sieving box

Modal orders	Frequency (Hz)	Characteristic of oscillation modes
1	2.50	Motion of rigid body parallel with *X* axis
2	2.91	Motion of rigid body parallel with *Z* axis
3	3.18	Torsion vibration rounding *X* axis
4	5.37	Pitching vibration rounding *Y* axis
5	60.36	Torsion vibration rounding *Z* axis
6	69.68	Torsion vibration rounding *X* axis
7	151.8	Bending vibration of the sieve plate
8	156.55	Bending vibration of the *L*-type reinforced plate near the outlet
9	178.63	Bending vibration of the *L*-type reinforced plate near the outlet
10	189.97	Bending vibration of the *L*-type reinforced plate near the outlet

4.3 Dynamic Response Analysis of the Sieving Box

During its working process, the drilling fluid shale shaker bears such large loads as gravity, vibration exciting force, elastic force and damping force. Because the shaker is an inertia shaker, so the elastic force and damping force can be neglected. The two side boards and reinforced beams bear most forces. The loads of the reinforced beams are equispaced inertia force, its gravity and bending moment transfered by the side boards. The loads of the side boards are vibration exciting force, equispaced inertia force, supporting force and bending moment transfered by the reinforced beams. It is a combination of planar stress and planar bending stress.

Applying the structure analysis module of CATIA software, we can get the dynamic response of the sieving box. According to the time course curves of displacement, stress, strain, we can get the dynamic changing. From Fig. 6, during its working process, the drilling fluid shale shaker has four stress concentrator regions, the side board approaching the outlet and the supporting board of the spring, the side board approaching the inlet and the supporting board of the spring, the connection part of the *L*-type reinforced board and the side board, the top hem and bottom hem approaching the inlet and outlet. The maximal main stress locates at the connection part of the side board approaching the outlet and the supporting board of the spring, its value is 42.2 MPa.

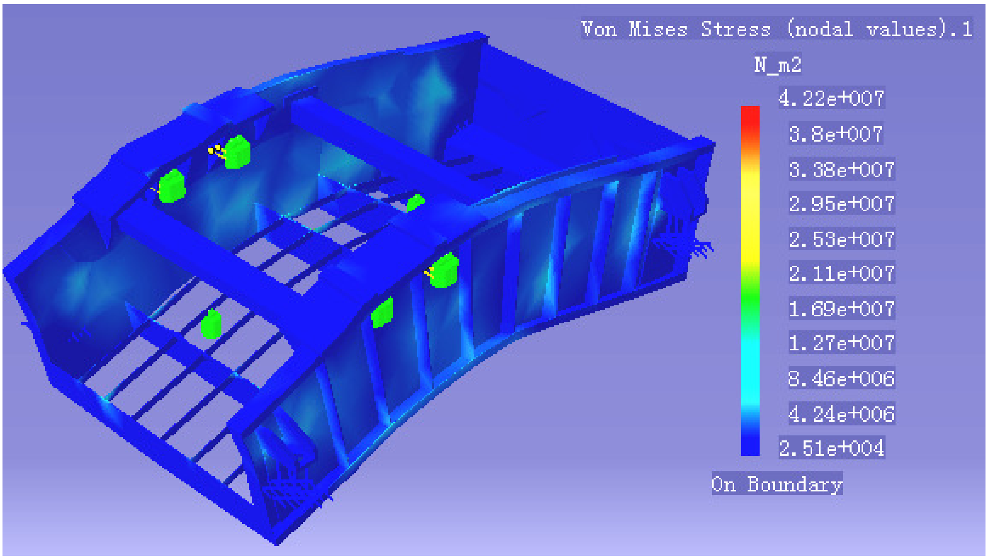

Fig. 6. Maximal main stress of the sieving box

5. Dynamic Strength Analysis of the Sieving Box

For complex plate structure of the sieving box, a general method for calculating its strength is difficult. Here, we adopt the finite element calculation of the maximum main stress to analyse the strength of the sieving box in bearing alternating stress of symmetrical circulation.

The thickness of the side boards is 5 mm, and its material is Q235 steel. In symmetrical circulation [22, 23]:

$$(\sigma_{-1})_d = \frac{\beta \varepsilon_\sigma}{K_\sigma} \sigma_{-1}, \tag{15}$$

$$\sigma_{-1} = 0.3(\sigma_s + \sigma_b), \tag{16}$$

where β is coefficient of surface quality, K_σ is effective stress concentration factor, ε_σ is size coefficient, σ_{-1} is fatigue limit in symmetrical circulation, σ_s is yield limit, σ_b is tensile limit.

Because the side boards are hot-rolled steel plates, so, $\sigma_s = 240$ MPa, $\sigma_b = 380$ MPa, β = 0.85, K_σ = 1.41, ε_σ = 0.70 [24]:

$$\sigma_{-1} = 0.3(\sigma_s + \sigma_b) = 0.3 \times (240 + 380) = 180 \text{ MPa},$$

$$(\sigma_{-1})_d = \frac{0.85 \times 0.70}{1.41} \times 180 = 76 \text{ MPa},$$

$$[\sigma_{-1}] = \frac{(\sigma_{-1})_d}{n} = \frac{76}{1.7} = 44.71 \text{ MPa},$$

where $[\sigma_{-1}]$ is allowable stress, n is allowable safety coefficient, $n = 1.7$.

During its working process, the maximum main stress of the sieving box is 42.2 MPa, which is less than the allowable stress, so its dynamic strength is satisfied.

6. Conclusions

When the force center of the vibrating forces coincide with the quality center of the vibrating quality, the balanced elliptical motion of the sieving box will be realized. From the simulation results of kinetic characteristic, the motion path of the sieving box is balanced ellipse.

The low-order modalities of the drilling fluid shaker are dense. They are rigid oscillation modes, mainly are whole translation, pitching vibration, torsion vibration. The high-order modalities are elasticity bending deformation. From the seventh-order oscillation mode, the bending deformation of the side board is large. From the eighth-order, ninth-order, tenth-order oscillation modes, the bending deformation of the *L*-type reinforced board near the outlet is large, so it should be strengthened. But as a whole, the frequencies of high-order modalities are higher than the working frequency, so it can not result a resonance vibration. All shows that, its structure design is reasonable. In the starting course of the shaker, effective measure should be adopted to avoid a resonance vibration. Of course, we can modify the structure locally, the modal frequency will redistribute, so it can not result a resonance vibration.

During its working process, the drilling fluid shaker has four districts of stress concentration, but the maximal main stress is less than the allowable stress of the side board, so the dynamic strength of the sieving box is enough.

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