Dynamic properties of vibration crusher of feed grain taking into account technological loading

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Abstract. The mathematical model of working elements of the feed grain vibration crusher considering its design features and interaction of working elements with process environment is obtained. Numerical experiments show the possibility of receiving the required dynamic property of a crusher with sufficient vibration amplitude of its working elements. The vibrations are synchronous and antiphase, which positively affects the efficiency of a crusher. It is also found that the crusher operates in a superresonance mode.

1. Introduction
Crushing of feed grain is mandatory for the preparation of compound feeds and wet feed mixes for all species of animals. Crushing of feed grain is quite energy-intensive, at the same time strict zootechnic requirements are set to fineness and evenness of groats particles by size.

The above explains continuous search for new designs of feed grain crushers. Altai State Agricultural University studies vibroimpulsive crushing of feed grain. The positive crushing effect was gained on a crusher with two crushing cavities.

This work studies a crusher design with two self-synchronized centrifugal vibration generators. According to fundamental principles of designing technological vibration and vibroimpulsive machines [1-3], this drive allows creating an energy-saturated machines and thus increasing productivity and compactness of the feed grain crusher.

2. Materials and methods
Working elements of a crusher (Figure 1) include an active element in the form of basket (1) with vibroactivators (2) installed on it and a passive element (3) representing a massive pendulum (3), which is kinematically connected to an active element (1) in a pendulum support (4).

Active element (1) can make angular vibrations in a drawing plane since it has an articulated suspension (5). At the top there is a bunker (6), where parent feed grain is filled into.

While crushing the grain expires from a bunker (6) to active zones between working elements (1) and (3), under the influence of which the parent grain is crushed. The crushing degree is regulated by changing the kinetic momenta of eccentric mass of centrifugal vibroactivators (2).

Such designs are successfully used to crush different rocks [1].
In general, the design of this crusher represents a symmetric system with two symmetry axes. The centrifugal vibroactivators in such systems are always self-synchronized [4], therefore we may say that the active element (1) (basket) is under the influence of the total coercive force of two centrifugal vibroactivators (Figure 1).

\[ \Phi = 2\Phi_0 \sin \omega t, \]

where \( \Phi_0 = m_D \varepsilon \omega^2 \) – centrifugal force of one vibroactivator (\( m_D, \varepsilon, \omega \) – weight, eccentricity of eccentric mass and angular speed of unbalanced mass shaft).

Figure 1. Operational scheme of a feed grain vibration crusher

Let us present the design scheme of a vibration crusher in the form of a double pendulum (Figure 2). The first pendulum suspended in point 0₁ is comprised of a weightless plate (1) with an active element (basket) (2), which is tightly attached to it. The second (passive) pendulum is formed by a massive plate (3) fixed in a point of suspension 0₂. The whole design in general and pendulums separately can make angular vibrations in the drawing plane.

Figure 2. Design scheme of angular vibrations of a crusher’s working elements.
The crushed feed grain is a relatively soft material with elastic and viscous properties. Therefore, let us model the layer of feed grain subjected to compression and crushing in a gap of working elements (2) and (3) in the form of elastic and viscous elements (Figure 2). This approach is also accepted in work [5].

3. Findings

Let us generate the differential equations. Let us assume that the gravity centers of pendulums coincide in quiescent state, i.e. that \(0, C_1 \approx 0, C_2 \approx 0, C \approx L\) (Figure 2).

The equation of forced vibrations of the first (external) pendulum will be as follows:

\[
I_1\ddot{\phi}_1 + b(\dot{\phi}_1 - \dot{\phi}_2)L + c(\phi_1 - \phi_2)L + MgL\sin \phi_1 = 2L\Phi_0 \sin \omega t
\]

(2)

where \(I_1\) – moment of inertia of a system in relation to point \(0\); \(M = m_1 + m_2 + 2m_p\) – total weight of the first and second pendulums and two balance weights; \(b, c\) – coefficients reflecting viscous and elastic properties of a grain layer.

Apparently, the equation (2) considers the elastic force of a grain layer

\[
P_e = c\psi = c(\phi_1 - \phi_2)
\]

(3)

and the viscous force of this layer

\[
P_v = c\dot{\psi} = c(\dot{\phi}_1 - \dot{\phi}_2)
\]

(4)

These forces characterize technological properties of the crushed feed grain.

The source of forced vibrations of the second pendulum, except forces transmitted through a grain layer, are the vibrations of its point of suspension \(O_2\) excited by the first pendulum. In other words, the vibrations of the second pendulum are also caused by the force of moving space

\[
J_e = -m_2(\ddot{x}\cos \phi_2 + \dot{y}\sin \phi_2).
\]

(5)

where \(\ddot{x}\) and \(\ddot{y}\) – accelerations of transportation motions in horizontal and verticals direction respectively.

Considering the above, let us write down the differential equation of angular vibrations of the second pendulum in relation to point \(0_2\) as follows:

\[
I_2\ddot{\phi}_2 + b(\dot{\phi}_2 - \dot{\phi}_1)L + c(\phi_2 - \phi_1) + m_2gL\sin \phi_2 = -m_2J(\ddot{x}\cos \phi_2 + \ddot{y}\sin \phi_2).
\]

(6)

Due to small vibrations we get:

\[
\sin \phi_1 \approx \phi_1; \sin \phi_2 \approx \phi_2; \cos \phi_2 \approx 1; \ddot{y} \approx 0; \ddot{x} = (L - l)\ddot{\phi}_1
\]

Then the equations (2) and (6) will be presented in a simplified form (let us also consider that \(\Phi_0 = m_2\epsilon\omega^2\))

\[
I_1\ddot{\phi}_1 + bL(\dot{\phi}_1 - \dot{\phi}_2) + cL(\phi_1 - \phi_2) + MgL\phi_1 = 2m_2\epsilon\omega^2L\sin \omega t
\]

(7)

\[
I_2\ddot{\phi}_2 + bL(\dot{\phi}_2 - \dot{\phi}_1) + cL(\phi_2 - \phi_1) + m_2gL\phi_2 = -m_2J(L - l)\ddot{\phi}_1.
\]

(8)

Having divided all members of the first equation by \(I_1\) and of the second by \(I_2\), we will get

\[
\left[\ddot{\phi}_1 + \frac{2n_1(\dot{\phi}_1 - \dot{\phi}_2) + \omega_{11}^2(\phi_1 - \phi_2) + \omega_{12}^2\phi_1}{\omega_1^2}\right] + \frac{\alpha_{11}n_1(\phi_1 - \phi_2) + \alpha_{12}n_1\phi_1}{\omega_1^2} = K_1 \cdot \omega^2 \sin \omega t
\]

(9)

\[
\left[\ddot{\phi}_2 + \frac{2n_2(\dot{\phi}_2 - \dot{\phi}_1) + \omega_{21}^2(\phi_2 - \phi_1) + \omega_{22}^2\phi_2}{\omega_2^2}\right] + \frac{\alpha_{21}n_2(\phi_2 - \phi_1) + \alpha_{22}n_2\phi_2}{\omega_2^2} = -K_2\ddot{\phi}_1
\]

where \(n_1 = \frac{bL}{2I_1}; n_2 = \frac{bL}{2I_2};\)

\[
\alpha_{11} = \sqrt{\frac{MgL}{I_1}}; \omega_{12} = \sqrt{\frac{cL}{I_1}}; \omega_{11} = \sqrt{\frac{cL}{I_1}};\]

\[
\alpha_{21} = \sqrt{\frac{MgL}{I_2}}; \omega_{22} = \sqrt{\frac{cL}{I_2}}; \omega_{21} = \sqrt{\frac{cL}{I_2}}; K_1 = \frac{2m_2\epsilon\omega L}{I_1}; K_2 = \frac{m_2J(L - l)}{I_2}.
\]

Values \(\omega_{12}\) and \(\omega_{21}\) correspond to angular frequency of vibrations. They express partial agents caused by elasticity of a grain layer in relation to partial frequencies \(\omega_{01}\) and \(\omega_{02}\) of free vibrations of pendulums in the gravity field.
The equation (9) represents the mathematical model of vibrations of crushing working elements taking into account technological loading. In principle, these equations can be solved for a stationary case via the analytical method, but lead to a cluttered appearance. Considering the above, the numerical solution allowing analyzing the processes of fixing the vibrations is more preferable. Figure 3 shows angular motion of working elements $\varphi_1 = \varphi_1$ and $\varphi_2 = \varphi_2$, as well as the angle of their joint vibrations $\psi = \varphi_1 - \varphi_2 = \varphi_1 - \varphi_2$. The estimated parameters of crushing are thus used: $\omega = 150 \, \text{c}^{-1}$; $\omega_1 = 5.0$; $\omega_2 = 2.0$; $\omega_2 = 2.6$; $\omega_2 = 4.5$; $n_1 = 0.67$; $n_2 = 2.0$; $K_1 = 0.033$; $K_2 = 0.500$.

Figure 3 shows that the scope of joint vibrations of working elements surpasses the scope of active and passive pendulums taken separately. This means that vibrations of working elements happen in the antiphase, i.e. at phase shift $\delta \to \pi$. At the same time the superresonance mode of vibrations is implemented, and hence through acceleration when exciting frequencies are small the system passes through resonances characterized by high vibration amplitudes of both pendulums.

![Figure 3](image-url)

**Figure 3.** Angular vibrations (in radians) of active $\varphi_1$, passive $\varphi_2$ pendulums and their mutual angular movements $\psi = \varphi_2 - \varphi_1$

It is clear that the design of a crusher shall consider the adjustable balance weights ensuring smooth increase of their static moment and excitation force through acceleration of the electric drive.

4. Conclusion

Thus, the mathematical model of working elements of the feed grain vibration crusher considering its design features and interaction of working elements with process environment is obtained.
Numerical experiments show the efficiency of the dynamic scheme of a crusher with sufficient vibration amplitude of working elements. The vibrations of working elements are synchronous and antiphase, which positively affects the efficiency of a crusher.

References
[1] Veisberg L A 2004 *Vibrating crushers. Principles of calculation, design and technological application* (SPb.: ARRIGS publishing house) p. 306
[2] Kartavy A N 2009 Resource-saving principles of designing technological vibration machines *Mining Equipment And Electrical Engineering*. 3 28–32
[3] Krupenin V L 2009 Shock and vibroshock machines and devices *Messenger of Scientific And Technical Development*. 4 3–32
[4] Blekhman I I 2013 *Theory of vibration processes and devices* (SPb.: Ore and metals) p. 640
[5] Shishkin E V Dynamics of vibration cone crusher *Automated Design In Mechanical Engineering* 3 82–87