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Design Calculations for Vibration Mixer Chain Drive

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Abstract. Application of vibration provides possibility for production of high-quality harsh concrete mixtures thanks to the thixotropic effect. A variant of a vibration mixer is given as implemented in a commercial prototype. Features of the device are considered. A method for chain drive calculation is given.

1. Introduction

It is widely known that application of vibration allows one to significantly intensify preparation of different polydisperse systems [1]. The most effective method is to use eccentric vibrating activators where the oscillations are induced by a kinematic method [2]. Stable vibration amplitude is among its advantages. In combination with constant frequency, it provides stable intensity of processing for stocks with diverse structural and rheological characteristics (granulometric composition, type of binder, etc). The methods developed to calculate balanced eccentric vibration activators [3] allowed creating a range of commercial prototypes of a vibration mixer, which confirmed their expediency and effectiveness in practice.

2. Current situation

Experience with calculations and operation of vibration mixers with eccentric vibration activators has shown that they provide necessary balance of the mechanism (equilibrium of oscillating masses). As a result of that, dynamic loads of the mixer elements, as well as those of external objects (body, personnel, structures, etc) are within the limits of the standard.

The work tool itself serves as a vibration activator and is supported on the drive shaft by connecting rod bearings. One of the bearings is eccentric. Dynamic balancing of the oscillating masses is ensured by counterweights (Figure 1).

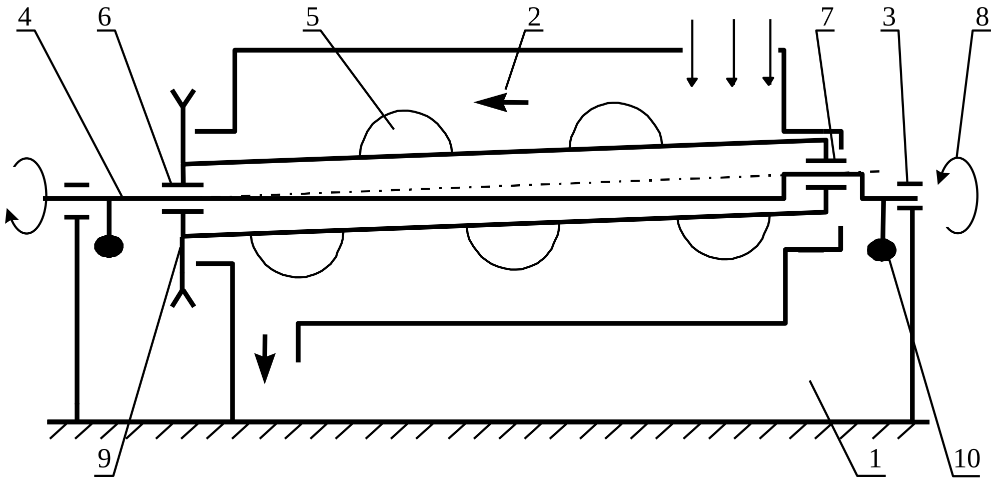

Figure 1. Diagram of vibration mixer. 1 – body, 2 – mixed material, 3 – main bearings, 4 – drive shaft, 5 – work tool (screw), 6 – connecting rod bearing, 7 – eccentric connecting rod bearing, 8 – drive system, 9 – drive sprocket, 10 – counterweights.

In this mixer, the driven sprocket of the screw drive is located in the zero eccentricity location of the connecting rod bearing case; as a result of shaft deflection and inaccuracies of fabrication, it oscillates with a certain displacement amplitude. The measurements of production mixers show that such displacements amount to 0.1...0.2 mm. As a result, significant dynamic loads arise in the chain drive due to pulsating changes in the driving strand longitudinal force leading to parametric oscillation of the chain drive.

To reduce the dynamic loads and chain oscillations, it is proposed to install a tensioner consisting of two spring-loaded sprockets: one – on the driving strand, another one – on the driven strand.

3. Analysis methodology

A computational model was analyzed to find out the influence of an additional spring-loaded sprocket on the driven strand (Fig. 2).

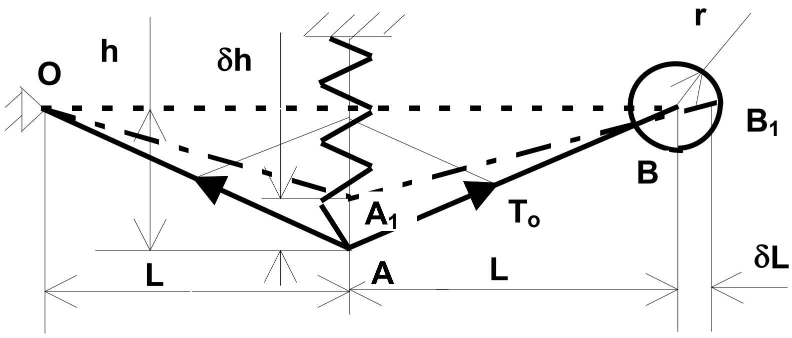

Figure 2. Computational model.

The driving sprocket is located at point O, the driven sprocket is at point B, which execute circular oscillations with the amplitude of $\delta L = r \cos\omega t$.

In this case, tension T(t) of the chain is equal to:

$$T(t) = T_o + \delta T(t),$$

where T_o is the tension of the chain caused by the operating load; $\delta T(t)$ is a variable component.

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To determine the variable component, two states were considered: OAB (State I) and OA_1B_1 (State II).

Supposing that the chain is inextensible, let us get the chain length values being equal in both states and from the geometric ratios which one may determine as:

$$\delta h = \frac{L\delta L}{2h} = \frac{Lr\cos\omega t}{2h}.$$

From an equilibrium condition between the spring tension and chain tension:

in State I, $T_0 = \dfrac{Lkl_0}{2h}$;

in State II, $T_1 = \dfrac{Lk(l_0+\delta h)}{2(h-\delta h)}$,

where T_0 and T_1 are chain tension values, k and l_0 are spring stiffness and deformation (in State I).

Then,

$$\delta T(t) = T_1 - T_0 = \frac{kL^2 r(l_0+h)}{4h^3}\cos\omega t;$$

and thus,

$$T(t) = T_0\left(1 + \frac{Lr(l_0+h)}{2h^2 l_0}\cos\omega t\right).$$

Stability of natural oscillations of the driving system may be analyzed if one replaces the real chain with a string (the accuracy is enough for practical calculations) [4]. Then, the task of determining transverse oscillations for this case is given by:

$$T(t)\frac{\partial^2 y_{1,2}}{\partial x^2} - \rho F\frac{\partial^2 y_{1,2}}{\partial t^2} = 0,$$

with limit conditions in points O $(x=0)$ and B $(x \cong 2L)$: $y_1(0) = 0$; $y_2(2L) = 0$ and matching conditions in point A $(x \cong L)$: $y_1(L)=y_2(L)$

$$T(t)\left(\frac{\partial y_1}{\partial x} - \frac{\partial y_2}{\partial x}\right)\Bigg|_{x=L} = ky_1(L).$$

If we are to solve the problem formulated as $y_{1,2}(x,t) = U(t)f_{1,2}(x)$, then it is possible to divide variables:

$$\frac{\dfrac{d^2 f_{1,2}}{dx^2}}{f_{1,2}} = \frac{\rho F\dfrac{d^2U}{dt^2}}{T(t)U(t)} = -\lambda, \qquad (1)$$

where λ is a certain constant.

From formula (1), two equations may be obtained:

$$\frac{d^2U}{dt^2} + \frac{\lambda T(t)}{\rho F}U = 0; \qquad (2);$$

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$$\frac{d^2 f_{1,2}}{\hat{a}x^2} + \lambda f_{1,2} = 0 \qquad (3).$$

Equation (2) shows the oscillating nature of the process, while equation (3) determines eigenvibrations.

Solution of the second equation leads to a system of two equations:

$$1) L\sin\sqrt{\lambda} = 0; \ldots 2) Ltg\sqrt{\lambda} = \frac{2T_0}{k}\sqrt{\lambda}.$$

From the first one, it is possible to get $\lambda_n^{(1)} = \left(\frac{\pi n}{L}\right)^2; n = 1,2....$

Solutions of the second (transcendental) equation may be obtained numerically, e.g., in case $l_0 = h$, taking into account equation $T_0 = \frac{Lkl_0}{2h}$, equation $tg\sqrt{\lambda} = \sqrt{\lambda}$ is obtained, and thus:

$$\lambda_1^{(2)} = \left(\frac{4{,}48}{L}\right)^2; \lambda_2^{(2)} = \left(\frac{7{,}72}{L}\right)^2; \lambda_n^{(2)} = \left(\frac{\pi/2 + n\pi}{L}\right)^2,$$ when $n \geq 3$.

Further, it is necessary to move on to studies of equation (2), which characterized the oscillating process.

After variable change $z = \frac{1}{2}\omega t$, one may obtain:

$$\frac{d^2U}{dz^2} + \frac{4T_0\lambda}{\omega^2\rho F}\left(1 + \frac{Lr(l_0 + h)}{2h^2 l_0}\cos 2z\right)U = 0. \qquad (4)$$

Equation (4) is a Mathieu equation and is usually written down as:

$$\frac{d^2U}{dz^2} + (a + 2q\cos 2z)U = 0. \qquad (5)$$

In this concrete case:

$$a = \frac{4T_0\lambda}{\omega^2\rho F}; \frac{2q}{a} = -\frac{Lr(l_0 + h)}{2h^2 l_0}.$$

From Mathieu function theory it is known that when values of parameters a and q are in the instability regions, solutions of the equation increase without limit with $z \longrightarrow \infty$. In the case under considerations, this corresponds to an unstable oscillation mode. With the help of a well-know Ince-Strutt diagram, it is possible to demonstrate that the oscillation mode will be stable if:

1. value of $\left|\frac{2q}{a}\right|$ is small;

2. parameter a does not coincide with squares of natural numbers for all $\lambda_n^{(1)}, \lambda_n^{(2)}$.

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4. Practical considerations

Selection of the spring is performed in the following way. Deformation value l_o is selected from design considerations; then the spring stiffness and its design characteristics are determined from known nominal force T_0 of the chain drive. Driven sprocket oscillation amplitude r within the limits of 0.1...0.2 mm and values of h and L are used to calculate parameters a, q, λ of the chain drive. If the conditions are met, the calculation is stopped. Otherwise, it is necessary to repeat the calculation from different starting conditions.

The calculations show that installation of an elastic bearing onto the driving strand of the chain drive provides changes in longitudinal stress in a wide range of parameters k, l_0, h, L with the longitudinal stress cycle asymmetry coefficient of 0.95...0.98 . The mode of oscillation is stable, because the value of $\left|\frac{2q}{a}\right|$ is small.

A chain drive of a commercial prototype of a vibration screw mixer has been designed in accordance with the proposed method of calculations. Performance testing confirmed correctness of the calculations. Installation of an elastic bearing provided a significant reduction of chain oscillations.

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