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TWO-MASS VIBRATING CONVEYER WITH NONPARALLEL FLAT SPRINGS

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Abstract. The analysis of operation of vibrating conveyers with nonparallel placement of flat springs is carried out. The motion of mechanical oscillating system is investigated. The structure of the supporting unit for flat springs fastening is propounded. This structure allows simplifying of setting-up of two-mass vibrating conveyers with the aim to ensure the effective operation.

The models of conveyers with nonparallel placement of springs, providing the accurate calculations of rigidities and angles of flat springs inclinations, considerably simplify the structures of conveyers and their setting-up to ensure the prescribed angles of vibrations.

The proposed structure of fastening of flat springs ends allows increasing of operation efficiency of the two-mass vibrating conveyer. Due to such setting-up of the equipment it is possible to compensate some of its theoretical and structural faults.

On the basis of presented investigations, it is planned to develop the three-mass models of conveyers-separators with transporting of separated components in different directions.

Introduction

Vibrating equipment including vibrating transporting machines has been widely and successfully used in various branches of industry during the last several decades [1; 2]. The especially intensive development of vibrating transporting equipment started in early 60-th of the previous century when in our country and abroad the wide range of various conveyers of different lengths and with different oscillations exciters (drives) was developed.

Thanks to the developments of scientific and research laboratory NDL-40 of Lviv Polytechnic National University this direction has gained new impetus since early 70-th of the 20-th century. Special achievements in this scientific direction belong to professor Povidailo V.O. and associate professor Shchyhel V.A., who together with engineers and scientists of the department of automation and laboratory NDL-40 considerably developed this direction of vibrotechnics. By concentrating on the development of models of vibrating conveyers with electromagnetic oscillations exciters (drives) and two-mass oscillating systems they developed, manufactured and applied in industry linear and tubular conveyers of large- and small-sized modifications with the range of transporting lengths from 0,1 m to 3,5 m. This conveyers were used as separate (autonomous) models and also were combined with various technological equipment. They can perform both transporting and technological functions, for example, drying, separation, dosing, mixing, fraction distribution of loose materials, products stacking etc.

The efficiency of use of vibrotransporting equipment with electromagnetic oscillations exciter (drive) is based on using of close to resonance operation modes, which allow development of simple structures with low power loss [2]. The development of branched and closed transporting and technological systems from separate transporting modules allows considerable improving and modernization of industry by ensuring large flexibility and by increasing its efficiency.

Problem statement

The most widespread models of the two-mass vibrating conveyers with electromagnetic drive are devices the structural scheme of which is presented in Fig. 1.

The conveyer consists of two oscillating masses which are placed one above the other. The working transporting mass includes transporting element 1 and armature 4. Reactive mass consists of the mass 2 (it may be transporting or not transporting) and electromagnet 3 which are fastened by flat springs 5 with a help of inserts 6 and side-frames 8. The structure is supported by immovable (stationary) base 9 with a help of soft dampers placed under the inserts 6. The special feature of this model consists in the fact that the line, which attaches the centers of oscillating masses O_1 and O_2, is perpendicular to the springs planes, i.e. the line coincides with the oscillations direction which is defined by the angle of vibration Ψ [2]. In the case when this condition is not satisfied except harmonic linear oscillations at the angle Ψ the additional "parasitic" oscillations around the combined gravity center O of the system raise along the transporting elements. This phenomenon is not admissible in most cases because the conveyer does not perform the functions of through transportation except the situations, when it is technologically planned to obtain uniformly variable motion, which may be influenced by the values of angular oscillations [4]. Presented above requirement to the placement of the masses centers O_1 and O_2 of the conveyer not always may be easily designed. This fact is related with the overall dimensions of the conveyer (the length of the transporting element which is prescribed by the technical conditions) and with the vibration angle Ψ, which is to be defined according to the recommendations [2].

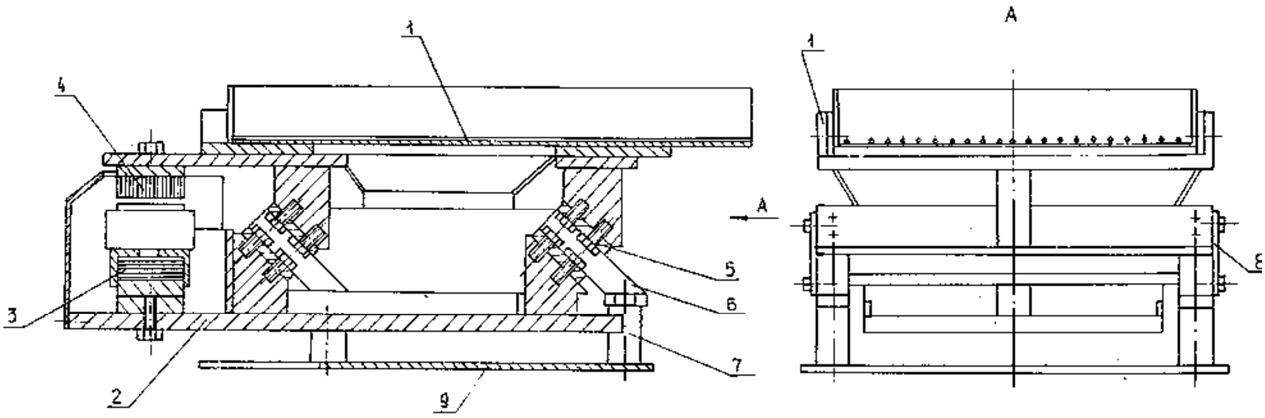

Fig. 1. *Structural scheme of two-mass vibrating conveyer with parallel placement of springs*

The satisfaction of the condition by means of structure redesigning leads to the forced increase of values of oscillating masses. This fact contradicts the theory of structure optimization. Based on this fact the problem of development of conveyers with the placement of oscillating masses one above another according to the prescribed technical conditions is raised. During the conveyer operation every particle of the working transporting part circumscribes the trajectory with the same parameters. This situation is possible to realize when there is nonparallel placement of two or more springs places in a certain way [5–8].

Analysis of modern information sources on the subject of the article

The problem of development of conveyers with nonparallel placement of flat springs has been investigated by the wide range of researchers. The results obtained by them are presented in publications [5; 6; 7] and patents [8; 9]. It is not certainly known about the realization of their achievements in practical structures, which may be applied in industry. The described experimental models have not been demonstrated on scientific shows or conferences. Recently the development of vibrotechnics has considerably slowed down in our country because of objective and subjective reasons, while the achievements of foreign researchers are little known. That is why in this article the authors decided to recur to the models with nonparallel placement of springs because there is a problem of development of simple models of vibrating conveyers.

Statement of purpose and problems of research

The main aim of this investigation is analysis and investigation of the two-mass vibrating conveyer with nonparallel placement of flat springs and electromagnetic oscillations exciter (drive) when the oscillating masses are arbitrary placed one above another. The results of investigations should considerably simplify the process of conveyer setting-up to ensure the uniform and uniformly variable motion along the transporting length.

Main material presentation

The complication of setting up of vibrating conveyers to ensure the effective operation consist in accuracy of determination of geometrical parameters of elements of mechanical system, their structural parameters and manufacturing technology [1; 2; 5].

Structural scheme of the conveyer with nonparallel placement of springs (Fig. 2) consists of the working (transporting) mass 1, which is fastened with reactive mass 2 by two nonparallel flat springs 3 and 4. With a help of soft dampers 5 the conveyer is placed on the base. As a drive of oscillations the electromagnetic vibration exciter is assembled. The electromagnet 6 is placed on the mass 2 and the armature 7 is placed on the mass 1.

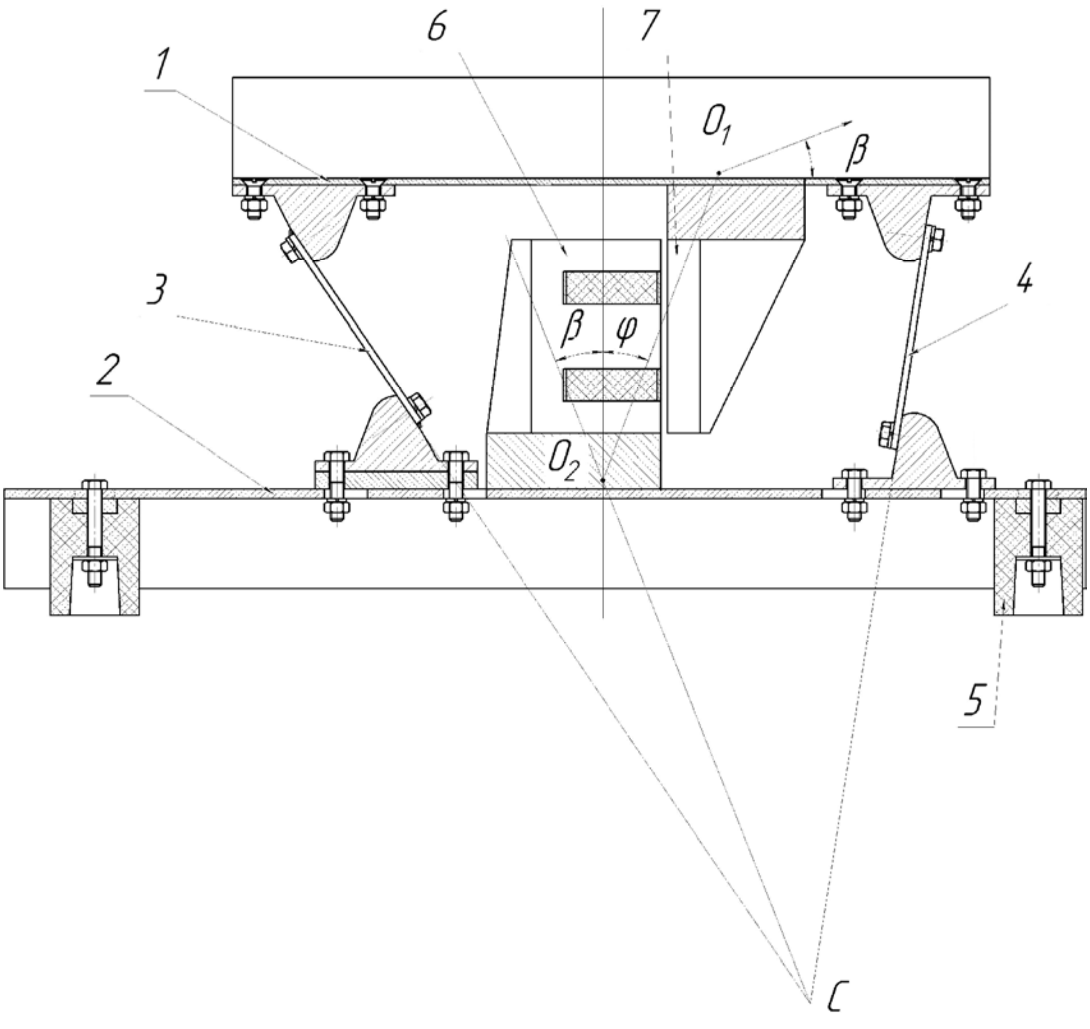

Fig. 2. *Structural scheme of vibrating conveyer with nonparallel placement of springs*

Let us consider the motion of the mechanical system under the influence of exciting force of electromagnetic drive. Let us apply the resultant vectors and resultant moments of the inertial forces to the body 1 and reactive body 2:

$$\vec{\Phi}_1 = -m_1 \cdot (\ddot{x}_1 \cdot \vec{i} + \ddot{y}_1 \cdot \vec{j});$$
$$\vec{\Phi}_2 = -m_2 \cdot (\ddot{x}_2 \cdot \vec{i} + \ddot{y}_2 \cdot \vec{j}) = -m_2 \cdot [\left(\ddot{x}_1 + \ddot{q} + \ddot{\varphi}_1 \cdot l \cdot \sin\Psi\right) \cdot \vec{i} + \left(\ddot{y}_1 - \ddot{\varphi}_1 \cdot l \cdot \sin\Psi\right) \vec{j}];$$
$$\vec{M}_1 = -I_1 \cdot \ddot{\varphi}_1 \cdot \vec{k}; \quad \vec{M}_2 = -I_2 \cdot \ddot{\varphi}_2 \cdot \vec{k} = -I_2\left(\phi_1 \cdot l - \frac{1}{r} \cdot \ddot{q}\right) \cdot \vec{k}, \tag{1}$$

where $\vec{i}, \vec{j}, \vec{k}$ are the unitary vectors directed along the coordinates axes $Oxyz$; $\vec{\Phi}_1, \vec{\Phi}_2$ are the resultant vectors of the inertial forces; $\vec{M}_1, \vec{M}_2$ are the resultant moments of the inertial forces about the centers of corresponding bodies; m_1, m_2 are the values of the working and reactive masses; φ is the angle between the line of masses centers and the vertical line; φ_1, φ_2 are the angles of oscillations of the working and reactive masses; q is the direction along which the vector $\vec{\Phi}_2$ is directed.

By using the principle of Dalamber for the mechanical system we may deduce the equations of equilibrium:

$$\sum_{k=1}^{n} F_{kx} = 0: \ \Phi_{1x} + \Phi_{2x} = 0; \quad -m_1 \cdot \ddot{x}_1 - m_2 \cdot (\ddot{x}_1 + \ddot{q} \cdot \ddot{\varphi}_1 \cdot l \cdot \cos\Psi) = 0;$$
$$\sum_{k=1}^{n} F_{ky} = 0: \ -m_1 \cdot \ddot{y}_1 - m_2 \cdot (\ddot{y}_1 - \ddot{\varphi}_1 \cdot l \cdot \sin\Psi) = 0;$$
$$\sum_{k=1}^{n} M_{01}\left(\vec{F}_k\right) = 0: \ \Phi_{2x} \cdot l \cdot \cos\Psi - \Phi_{2y} \cdot \sin\Psi + M_1 + M_2 = 0; \tag{2}$$
$$-m_2 \cdot l \cdot \cos\Psi\left(\ddot{x}_1 + \ddot{q} + \ddot{\varphi}_1 \cdot l \cdot \cos\Psi\right) + m_2 \cdot l \cdot \sin\Psi \cdot (\ddot{y}_1 - \phi_1 \cdot l \cdot \sin\Psi) - I_1 \cdot \ddot{\varphi}_1 - I_2 \cdot \left(\ddot{\varphi}_1 - \frac{\ddot{q}}{r}\right) = 0.$$

After the grouping (collecting) and changing the signs we obtain the following differential equations:

$$\left(m_1 + m_2\right)\ddot{x}_1 + m_2 \cdot \ddot{q} + \left(m_2 \cdot l \cdot \cos\Psi\right)\ddot{\varphi}_1 = 0;$$
$$\left(m_1 + m_2\right)\ddot{y}_1 - m_2 \cdot l \cdot \sin\Psi \cdot \ddot{\varphi}_1 = 0; \tag{3}$$
$$\left(m_2 \cdot l \cdot \cos\Psi\right)\ddot{x}_1 - m_2 \cdot l \cdot \sin\Psi \cdot \ddot{y}_1 + \left(m_2 \cdot l \cdot \cos\Psi - \frac{I_2}{r}\right)\ddot{q} + \left(m_2 \cdot l^2 + I_1 + I_2\right)\ddot{\varphi} = 0.$$

In these equations the exciting forces have not been included $F_1 = F_2 = F \cdot \sin(\omega \cdot t)$ because their resultant vector and resultant moment are equal to zero.

Let us single out the reactive body 2 and apply to this body the inertial force, the exciting force $F_2 = F \cdot \sin(\omega \cdot t)$, reactions R_i and moments M_i of the influence of rejected springs (Fig. 3):

$$R_i = \frac{12EI_i}{l_i^3} \cdot \frac{r_i}{r} \cdot q + \frac{6EI_i}{l_i^2} \cdot \frac{h_2}{r};$$
$$M_i = \frac{6EI_i}{l_i^2} \cdot \frac{r_i}{r} \cdot q + \frac{4EI_i}{l_i} \cdot \frac{h_2}{r}, \tag{4}$$

where l_i is the length of springs; I_i is the moment of inertia of the springs cross-sections; E is the modulus of elasticity of the springs material; r is the distance between the point of crossing of lines of springs inclination and the masses center O_2; r_i is the distance between the point of crossing of lines of springs inclination and the masses center of the i-th spring; h_2 is the distance between the point of exciting force F_2 application and the masses center O_2.

By using Dalamber principle of once more let us derive the equation of moments about the point A:

$$\sum_{k=1}^{n}\left(\vec{F}_k\right) = 0; \ -\Phi_{2x} \cdot r + \mathrm{M}_2 + \sum_{i=1}^{S}\left(R_i \cdot r_i\right) + F_2 \cdot h_2 + F_2 \cdot \cos y \cdot r = 0. \tag{4a}$$

By dividing of equation (4a) on r and by substitution of the expressions of forces and moments we obtain the following differential equation:

$$m_2 \cdot \ddot{x}_1 + \left(m_2 + \frac{I_2}{r^2} \right) \cdot \ddot{q} + \left(m_2 \cdot l \cdot \cos\Psi - \frac{I_2}{r} \right) \cdot \ddot{\varphi} + \mathrm{K}_q \cdot q = -F \left(\cos y + \frac{h_2}{r} \right) \cdot \sin \omega t \,, \tag{5}$$

where K_q is the coefficient of rigidity which may be defined by the following formula:

$$\mathrm{K}_q = \frac{12\mathrm{E}}{r^2} \cdot \sum_{i=1}^{s} \frac{l_i \left(r_i^2 + l_i r_i + \frac{1}{3} \cdot l_1^2 \right)}{l_i^3} . \tag{6}$$

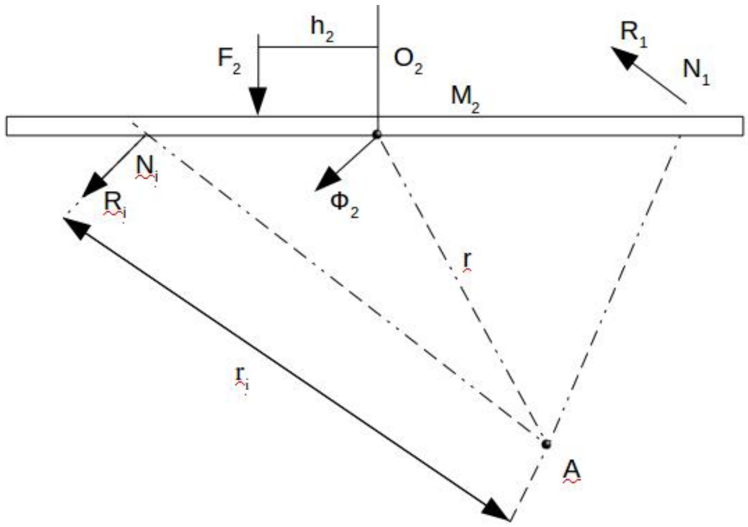

***Fig. 3.** Design diagram of the mechanical system*

The analytical investigation of motion of the reactive body absolutely confirms the results and statements carried out in the publications [5; 6; 7].

With the aim to simplify the setting-up of the two-mass vibrating conveyer and to ensure uniformly variable and uniform laws of the loading motion the structure of the supporting unit for fastening of flat springs ends is proposed (Fig. 4). The essence of the proposition consists in the following fact: the regulation of parasitic angular oscillations of mechanical system may be changed by turning of the hinged brackets axes. By using of this method of the vibrating conveyer setting-up the prescribed (specified) conditions of the parts and materials transporting may be achieved.

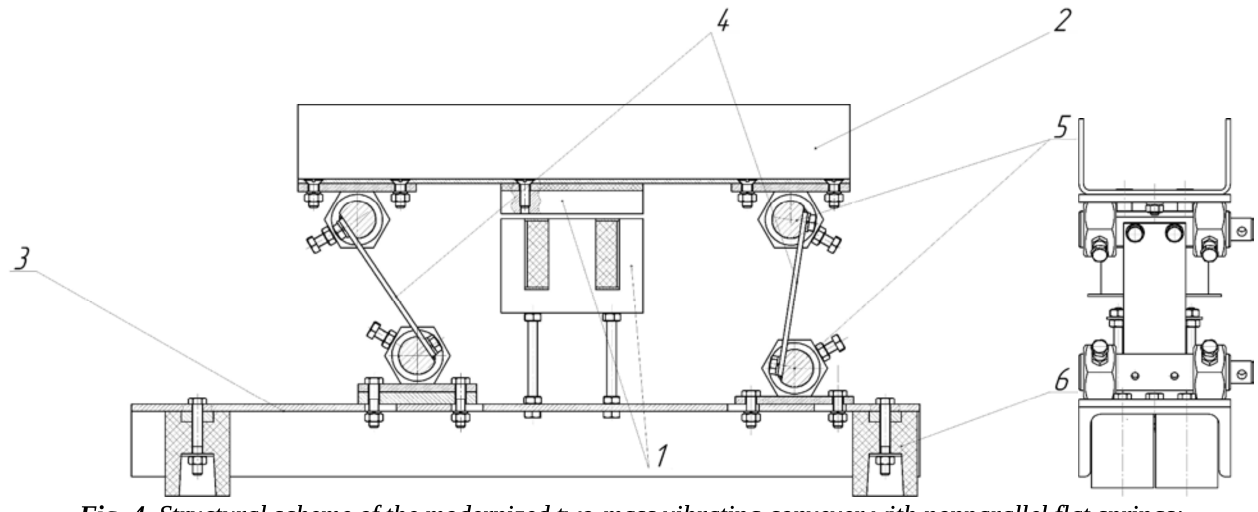

***Fig. 4.** Structural scheme of the modernized two-mass vibrating conveyer with nonparallel flat springs:*
1 – electromagnetic drive; 2 – working mass; 3 – reactive mass; 4 – springs; 5 – hinged brackets; 6 – vibroinsulators

According to the structural scheme (Fig. 4) the experimental model of the conveyer with nonparallel springs was designed and manufactured (Fig. 5).

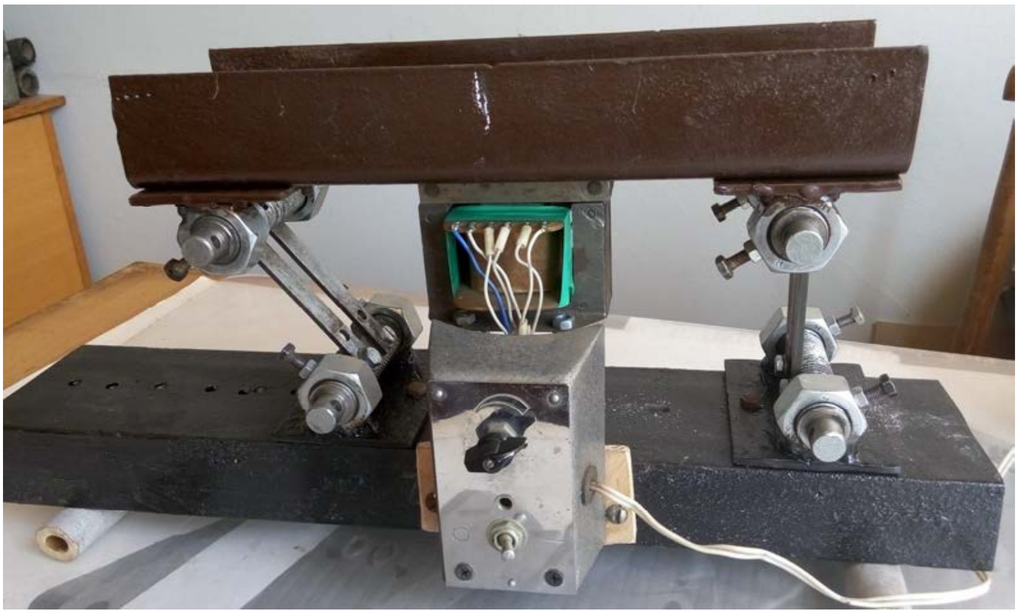

***Fig. 5.** Experimental model of the two-mass vibrating conveyer with nonparallel flat springs*

Conclusions

The models of conveyers with nonparallel placement of springs, providing the accurate calculations of rigidities and angles of flat springs inclinations, considerably simplify the structures of conveyers and their setting-up to ensure the prescribed angles of vibrations.

The proposed structure of fastening of flat springs ends allows increasing of operation efficiency of the two-mass vibrating conveyer. Due to such setting-up of the equipment it is possible to compensate some of its theoretical and structural faults.

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