ЕКСПЛУАТАЦІЯ ТА ВІДНОВЛЕННЯ ОВТ

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I. Vrublevskyi

Hetman Petro Sahaidachnyi National Army Academy, Lviv

INCREASING OF ELEVATION ANGLES IN VIBRATORY CONVEYOR WITH ELECTROMAGNETIC DRIVE

The design of conveyor intended for automation of inter-operational movement and supply of details and materials on the mechanized military enterprises and warehouses is considered. It is based on two-mass vibratory conveyor with independent electromagnetic drives of longitudinal and normal oscillations of conveying track and with horizontally mounted flat latticed springs. Electromagnetic drive allows implementing the optimal by velocity biharmonic normal oscillations of conveyor's working body with a certain value of natural frequency, which depends on the inclination angle of conveyor's track. The latticed springs are mounted between the working body and reactive frame of conveyor with the possibility to change the working length of springs and as a result the natural frequency of normal oscillations. The presented vibratory conveyor allows increasing the conveying velocity and the elevation angles, when the loads are moving up, without design's complication.

Key words: *vibratory conveyor, electromagnetic drive, elevation angle.*

Problem statement

Vibratory devices (conveyors, bowl feeders, elevators, manipulators), particularly the vibratory conveyors with the electro-magnetic drives, can be widely used in the military enterprises and warehouses for automation of the auxiliary operations, such as inter-operational movement, supply of details and materials to the processing and assembly positions. They allow moving the different types of cargo, differing in sizes, weight, including the fragile and explosive materials, not only horizontally but also upward on the definite height. For the conveying of such materials it is necessary to observe the non-jumping modes of moving. However, in these modes the most common vibratory conveyors with linear oscillations, possessing the simplicity of maintenance, reliability and possibility of re-adjustment, are characterized by the low conveying velocity and elevation angles, and as a result, the low productivity and insufficient lifting height.

The using of independent drives of longitudinal and normal oscillations may sufficiently increase the conveying velocity and elevation angles, especially with the using of biharmonic normal oscillations. Nevertheless, the existing designs of conveying devices implementing such oscillations are relatively complex.

Analysis of recent publications

Vibratory conveying devices have been considered in many scientific papers [1,2], particularly in dissertation [2] the advantage of using of harmonic longitudinal and biharmonic normal oscillations has been proved. Such oscillations with definite ratios of component's amplitudes and phase difference angles support the sufficiently increasing of the conveying velocity and elevation angles. This advantage is the most special for non-jumping modes. The existing designs of vibratory conveying devices implementing such oscillations are constructed on the basis of three-mass oscillating system, that's why they are relatively complex due to the presence of additional mass and additional drive of second harmonic of normal oscillations [3]. Author has offered the method of vibratory conveying [4], that lies in fact that biharmonic normal oscillations of vibratory conveyor with optimal by velocity ratio of component's amplitudes and phase difference angles are excited by the single electromagnetic drive with the definite value of natural frequency of normal oscillations, depending on elevation angle. So such optimal oscillations can be implemented in two-mass vibratory conveyor, for example in conveyor with the flat latticed springs [5]. However, it has the constant frequency of natural oscillations and with changing of elevation angle the springs need to be changed.

Aim of the article

The purpose of the paper is the design and development of two-mass vibratory conveyor with independent electromagnetic drives of longitudinal and normal oscillations that implements biharmonic normal oscillations with optimal by velocity ratio of component's amplitudes and phase difference angles depending on inclination angles of conveyor's track. The conveyor's design should provide the ability to change the natural frequency of normal oscillations with changing of inclination angle.

The main material presentation

Two-mass vibratory conveyor with independent electromagnetic drives of longitudinal and normal oscillations, the dynamic scheme of which is shown on Fig. 1, consists of the working body with mass m_2 and reactive frame with mass m_1 , that are connected with aid of elastic system in the form of flat latticed springs with stiffness in horizontal and vertical directions c_x and c_y respectively. Reactive frame is installed on the foundation using vibratory isolators, the stiffness of which is c_1.

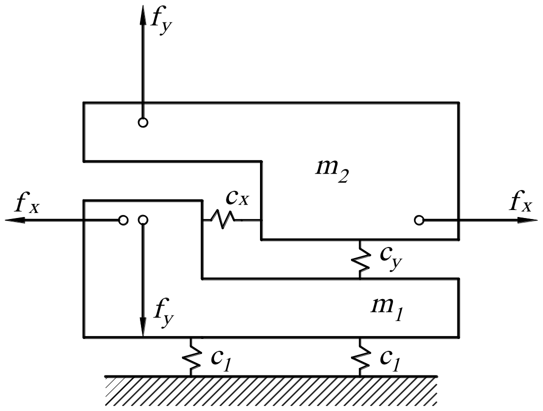


Fig. 1. **Dynamic scheme of two-mass vibratory conveyor with independent longitudinal and normal oscillations**

Due to the use of longitudinal (along the direction of conveying – with respect to coordinate x) and normal (perpendicular to track's plane – with respect to coordinate y) oscillations with phase difference angles, optimal by velocity, the vibration of conveyor's working body is implemented by the law:

$$x = A_x \cdot \sin(\omega t + \varepsilon)\,,$$
$$y = A_1 \sin \omega t + A_2 \cos 2\omega t\,, \qquad (1)$$

where A_x – amplitude of longitudinal oscillations, A_1 and A_2 – amplitudes of relatively first and second harmonics of biharmonic normal oscillations, $\omega = 2\pi\nu$ – circular frequency of forced oscillations, ν – cyclic frequency of forced oscillations, ε – phase difference angle, t – time. The stiffness of vibratory isolators is negligible relatively to the stiffness of elastic system, that is why we accept c_1=0. The natural frequencies of longitudinal and normal oscillations ν_x and ν_y relatively can be obtained by formulae [1]

$$\nu_x = \frac{1}{2\pi}\sqrt{\frac{c_x}{m}}\ , \quad \nu_y = \frac{1}{2\pi}\sqrt{\frac{c_y}{m}}\ , \qquad (2)$$

where $m = m_1\ m_2 \ / \ (m_1 + m_2)$ – reduced mass of vibratory conveyor.

According to theoretical and experimental investigations [6] the optimal by velocity ratio of harmonics' amplitudes A_1/A_2 of biharmonic normal oscillations may be obtained with a single electromagnetic drive that works in pre-resonant mode with the definite value of natural frequency $\nu_y=\nu_*$, that depends on parameter of inclination angle K_α , which is calculated by formula

$$K_\alpha = \frac{tg\alpha}{f}\,, \qquad (3)$$

where α – inclination angle of conveyor's track to horizon, f – coefficient of friction of conveying goods.

On common case of forced frequency ν=50 Hz for implementation of optimal vibration's law (1) two-mass vibratory conveyor with electromagnetic drive should provide the variable value of natural frequency of normal oscillations ν_y. The graph of optimal frequency of normal oscillations ν_* dependence on parameter of inclination angle K_α is shown on Fig. 2.

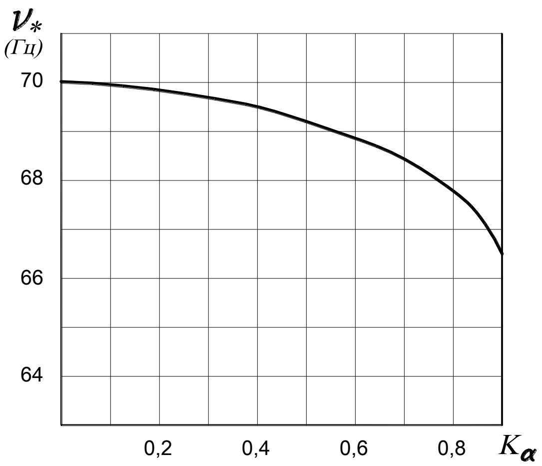


Fig. 2. **Dependence of optimal frequency of normal oscillations ν_* of vibratory conveyor on parameter of inclination angle K_α**

According to Fig. 2, this frequency should be from ν_y=70,1 Hz with horizontal conveying (K_α= 0) to ν_y=66,5 Hz with limited value K_α=0,9 (maximum angle when upward moving is possible). The value of natural frequency of longitudinal oscillations should be constant ν_x=52-53 Hz [1].

Elastic system of vibratory conveyor consists of the latticed springs 1 (Fig. 3) – the flat springs with the working length L, width B and thickness h , with n–1 longitudinal cut-outs by length l, that form n bars with width b. The latticed spring 1 is connected by its both ends to working body and reactive frame with aid of gaskets 2 with bolt connection. The spring has the oval slots 3, by virtue of which the gaskets may move relative to the spring, changing the working length L.

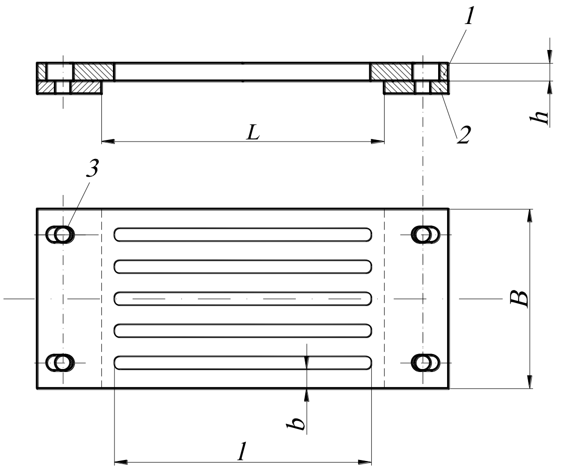


Fig. 3. **Element of elastic system – latticed spring**

The spring has stiffness in horizontal and vertical directions, and the last does not depend on the working length L of spring, but on the length l of bars. If the latticed springs would be mounted horizontally, the horizontal and vertical stiffness of elastic system of vibratory conveyor according to [7] can be calculated by formulae

$$c_x = \frac{inEhb^3}{l^3}, \; c_y = \frac{iEh^3}{\frac{L^3 - l^3}{B} + \frac{l^3}{nb}} \qquad (4)$$

where i – number of springs, E – Young's modulus.

If the working length L of springs can be changed, the value of natural frequency of normal oscillations ν_y changes without changing of natural frequency of longitudinal oscillations ν_x.

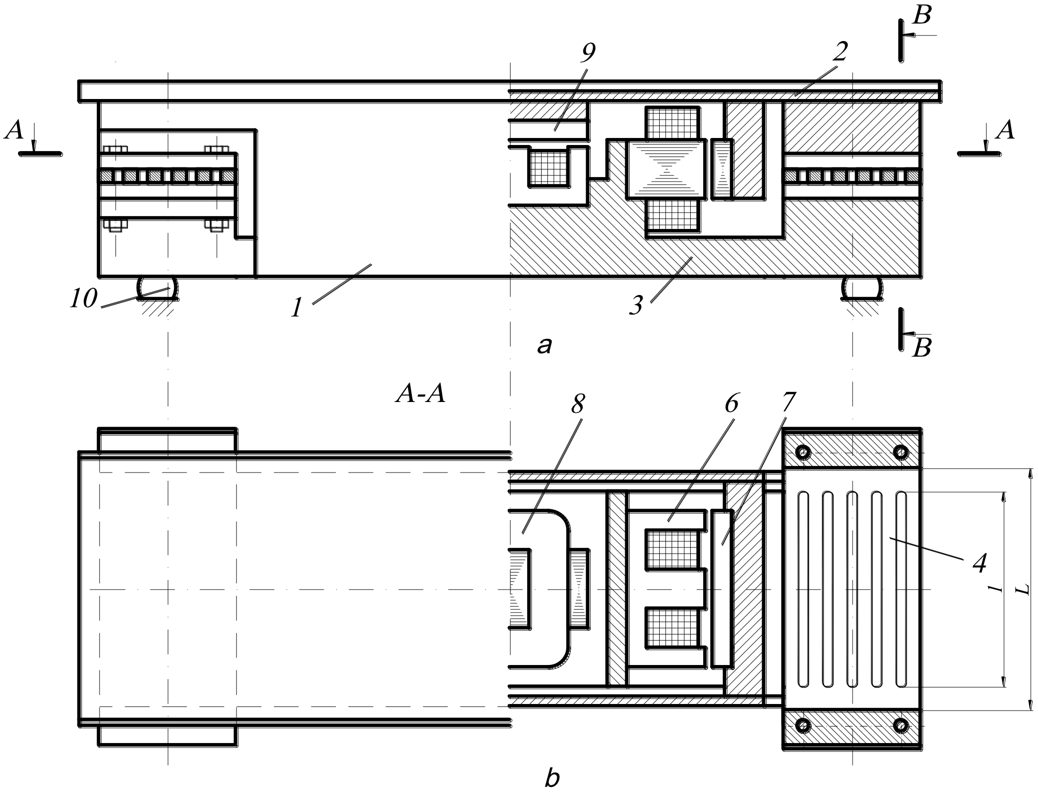


Fig. 4. **Design of two-mass vibratory conveyor with independent electromagnetic drives of longitudinal and normal oscillations and horizontally mounted latticed springs:**
a – main view, *b* – top view with slice *A-A*

Fig. 4 shows the design of two-mass conveyor with independent electromagnetic drives of longitudinal and normal oscillations and horizontally mounted latticed springs (Fig. 4a – main view, Fig. 4b – top view with slice *A-A*).

Fig. 5 shows left view of conveyor with slice *B-B*, Fig. 6 – system of the springs' working length operation with changing of track's inclination angle.

Vibratory conveyor (Fig. 4 and 5) consist of the working body's housing 1, to which the load-carrying track 2 is connected, and reactive frame 3. The working body and reactive frame are connected by two latticed springs 4. Vibratory drive of longitudinal oscillations consists of two electromagnets, which are mounted symmetrically with respect to the vertical axis of conveyor. The cores 6 of electromagnets are fastened to reactive frame 3 and their anchors 7 are fastened to housing 1. Vibratory drive of normal oscillations consists of core 8 of electromagnet, which is fastened to reactive frame 3, and anchor 9, which is fastened to housing 1. Reactive frame is installed on the foundation using vibratory isolators 10. Latticed spring 4 is mounted by the bolt connections through the gaskets 5 by one of its end to bracket 11 of working body's housing and by second one – to bracket 12 of reactive frame (Fig. 5). In the places of connection the latticed springs have oval slots that allow the gaskets 5 to move relative to the springs. The brackets 11 and 12 are supplied by marks relative to the value of parameter of inclination angle K_α.

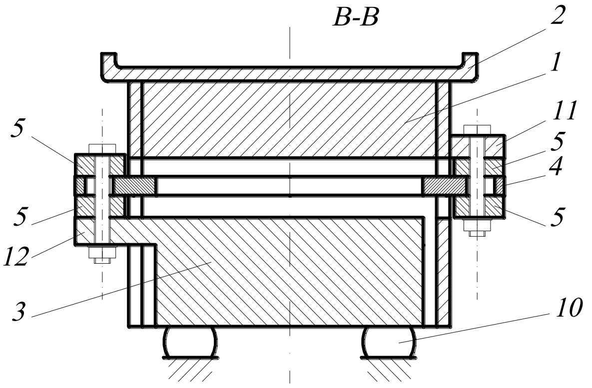
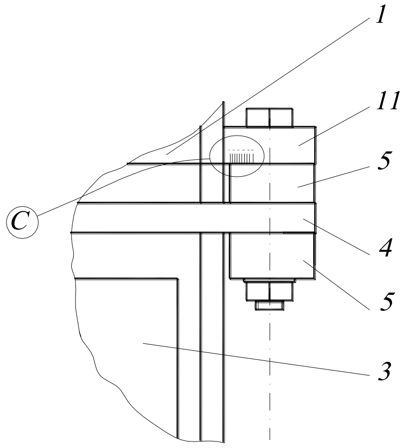


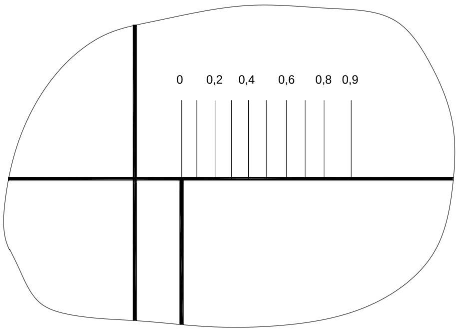
Fig. 5. **Design of two-mass vibratory conveyor (left view with slice *B-B*)**

Fig. 6a shows the system of springs' working length operation: spring 4 is fastened by bolt connection through the gaskets 5 to bracket 11. Fig 6b shows the marks on the bracket 11 in enlarged view (element *C*). The same marks are on the bracket 12 of reactive frame.



a

C (enlarged)



b

Fig. 6. **System of the springs' working length operation with changing of track's inclination angle**

Initially the springs are mounted to the brackets in a way to provide horizontal conveying (α=0º), i.e. the gaskets 5 are fixed opposite the marks of brackets 11 and 12, which are correspond with the value of parameter K_α=0 and therefore the value of natural frequency of normal oscillations 70,1 Hz. With the necessity of conveying upward and changing of inclination angle α it needs to change the working length of strings. For this purpose, knowing the values of the angle α and coefficient of friction *f*, it needs to calculate the value of parameter K_α by formula (3) and to fasten the springs 4, fixing the ends of gaskets 5 opposite the corresponding marks of the brackets 11 and 12. With changing of gaskets position corresponding to the marks, the working length *L* of springs changes and according to formulae (2) and (4) the stiffness and natural frequency ν_y of normal oscillations changes as well, though the stiffness and natural frequency ν_x of longitudinal oscillations stays unchanged. For saving the symmetry of elastic system the ends of all eight gaskets 5 must be fixed opposite the same marks of brackets 11 and 12.

Two-mass vibratory conveyor allows implementing the harmonic longitudinal and biharmonic normal oscillations of working body, optimal by velocity for different elevation angles.

Conclusions

The design of two-mass vibratory conveyor with independent electromagnetic drives of longitudinal and normal oscillations and horizontally mounted latticed springs is constructed. With definite value of natural frequency of normal oscillations, depending on inclination angle relative to horizon, electromagnetic drive implements optimal by velocity biharmonic normal oscillations. It allows sufficiently increasing the conveying velocity and elevation angles. With changing of inclination angle, it needs to change the natural frequency of normal oscillations. It is achieved by changing the working length of springs, moving the gaskets of bolt connection along the marking brackets of working body and reactive frame of conveyor.

Describing vibratory conveyor, created by preliminary calculations and adjustment may be effectively applied for industrial automation of military enterprises and warehouses, particularly for inter-operational movement and supply of details, massive, fragile and explosive materials to the processing and assembly positions of mechanized production.

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Збільшення кутів підйому вантажів у вібраційному транспортері з електромагнітним приводом

І. Врублевський

Розглянуто конструкцію двомасового вібраційного транспортера з незалежними електромагнітними віброзбуджувачами поздовжніх і нормальних коливань робочого органу і пружною системою у вигляді ґратчастих пружин, призначеного для автоматизації переміщення різноманітних вантажів, зокрема масивних або крихких, на військових підприємствах та складах. Плоскі ґратчасті пружини розташовані горизонтально і кріпляться своїми кінцями до кронштейнів робочого органу і реактивного каркаса за допомогою болтового з'єднання через прокладки, що дозволяють міняти робочу довжину пружин. При цьому змінюється власна частота нормальних коливань, в той час як власна частота поздовжніх коливань не міняється, що дає можливість роботи віброзбуджувача поздовжніх коливань у біляgreзонансному режимі для підтримання великої амплітуди коливань, а відповідно, і високої швидкості транспортування. Електромагнітний віброзбуджувач нормальних коливань, який працює у дорезонансному режимі (коли частота власних коливань суттєво більша за частоту коливань привода), дозволяє реалізувати оптимальні за швидкістю бігармонічні нормальні коливання робочого органу при певному значенні власної частоти, яка залежить від кута нахилу транспортної площини до горизонту. На кронштейнах робочого органу і реактивного каркаса нанесені мітки, що відповідають певним значенням параметра кута нахилу – відношенню тангенса кута нахилу до коефіцієнта тертя ковзання вантажу, напроти яких повинні встановлюватися прокладки кріплення пружин при зміні кута нахилу. Діапазон міток від 0 (при горизонтальному транспортуванні) до 0.9 (при максимальному куті, при якому можливе транспортування вгору). При зміні кута нахилу необхідно порахувати значення параметра кута нахилу та встановити кінці прокладок напроти відповідних міток. Для збереження симетрії пружної системи необхідно всі прокладки встановлювати напроти однакових міток. Представлений вібраційний транспортер дозволяє без ускладнення конструкції суттєво підвищити швидкість транспортування масивних вантажів та збільшити кути їх підйому при транспортуванні вгору.

Ключові слова: *вібраційний транспортер, електромагнітний привод, кут підйому вантажу.*

Увеличение углов подъёма грузов в вибрационном транспортёре с электромагнитным приводом

И. Врублевский

Рассмотрена конструкция двухмассового вибрационного транспортёра с независимыми электромагнитными вибровозбудителями продольных и нормальных колебаний рабочего органа и упругой системой в виде решётчатых пружин, предназначенного для автоматизации перемещения различных грузов, в т. ч. массивных или хрупких, на военных предприятиях и складах. Плоские решётчатые пружины расположены горизонтально и крепятся своими концами к рабочему органу и реактивному каркасу транспортёра с помощью болтового соединения через прокладки, позволяющие изменять рабочую длину пружин. При этом меняется собственная частота нормальных колебаний, тогда как собственная частота продольных колебаний остаётся неизменной, что даёт возможность работы электромагнитного вибровозбудителя продольных колебаний в околорезонансном режиме для поддержания большой амплитуды колебаний и соответственно высокой скорости транспортирования. Электромагнитный вибровозбудитель нормальных колебаний, работающий в дорезонансном режиме (когда частота собственных колебаний существенно больше частоты колебаний привода), позволяет реализовать оптимальные по скорости бигармонические нормальные колебания рабочего органа транспортёра при определённой собственной частоте, которая зависит от угла наклона транспортной плоскости к горизонту. На кронштейнах рабочего органа и реактивного каркаса нанесены метки, соответствующие определённым значениям параметра угла наклона – отношения тангенса угла наклона к коэффициенту трения скольжения груза, напротив которых должны устанавливаться прокладки крепления пружин при изменении угла наклона. Диапазон меток от 0 (при горизонтальном транспортировании) до 0,9 (максимальном угле подъёма, при котором возможно движение вверх). При изменении угла наклона необходимо посчитать значение параметра угла наклона и установить концы прокладок напротив соответствующих меток. Для сохранения симметрии упругой системы нужно все прокладки устанавливать напротив одинаковых меток. Представленный вибрационный транспортёр позволяет, не усложняя конструкцию, существенно повысить скорость транспортирования массивных грузов и увеличить углы их подъёма при транспортировании вверх.

Ключевые слова: *вибрационный транспортёр, электромагнитный привод, угол подъёма груза.*