Two-mass linear vibratory conveyor with reduced vibration transmission to the ground

Martin Sturm
Faculty of Mechanical Engineering, University of Applied Sciences Zittau/Görlitz, Zittau/Görlitz, Germany
E-mail: *m.sturm@hszg.de*

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Abstract. Linear vibratory conveyors are common equipment to convey goods. They are used in different industries such as for example the building, mining and food industry. The systems are mainly used for the supply of bulk goods into further processing operations. The goods to be conveyed, typically requesting a heavy-duty design of the conveyor and eccentric excitation drives with relatively high torque. A supply of strong vibrations to the floor is an effect, which often is caused by vibratory conveyors. The target of this article is to determine a dynamic model, based on a two-mass absorber system, helping to avoid the transfer of vibrations to the ground. An optimum supply of goods by the same time should be ensured.

Keywords: vibratory conveyor, dynamic absorber, resonance frequencies, dynamic model.

1. Introduction

Linear vibratory conveyors are mainly built to forward bulk material for the mining, building and food industry, such as rock, grit and flour. The assembly of these vibratory conveyors consists of two principal parts, the conveying element build as a conveying trough and a supporting element, build of steel elements and fixed to the ground by heavy-duty screws [1, 2]. These conveyors commonly representing one-mass systems. The disadvantage of one-mass systems is the limitation of possibilities to optimize the efficiency regarding the conveying of the goods and even more, the limitation in reducing the transmission of vibrations to the floor.

A two-mass conveyor as shown in Fig. 1 represents an alternative solution to a one-mass linear vibrating conveyor.
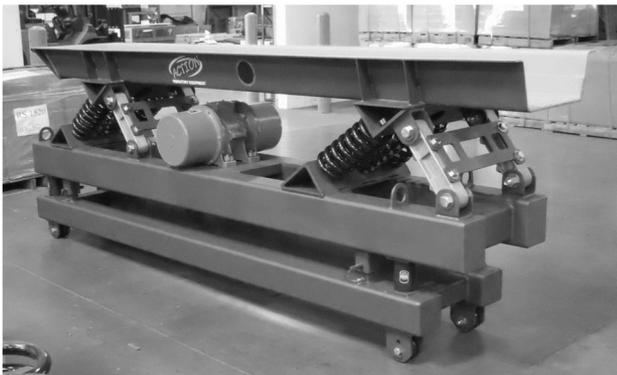
Fig. 1. Vibratory conveyor with two masses [3]

2. Applied methods

The theoretical solution is done in two steps. At first, a dynamic model is designed and then the dynamic parameters are determined.

2.1. Determination of the conveyors dynamic model

The assembly of the following two-mass vibratory conveyor consists of three principal parts,

the conveying element build as a conveying trough, represented by character m_2, the excited mass with the drive, represented by character m_1 and a supporting element, fixed to the ground. Both masses are connected by the use of springs. In this case, helical springs are chosen. The excitation of m_1 is done by an eccentric drive, installed to excite the mass 90° to the lever R_1 [4]. The springs with their particular stiffness are defined as k_1 and k_{21}. The damping of the system is neglected. Mass m_1 is connected to the ground by levers under an angle β_1, mass m_2 is connected to mass m_1 by levers under an angle β_2. The levers enabling a defined guidance of the masses motion. Fig. 2 shows the mechanical model of this two-mass conveyor.
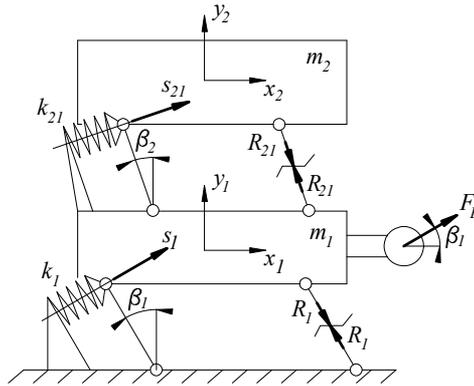

Fig. 2. Mechanical model of the vibratory conveyor

2.2. Calculation of dynamic parameters

Based on the mechanical model shown in Fig. 2, the following equations are formed [5]:

$$m_1\ddot{x}_1 + k_1x_1 - k_{21}x_{21} - F_{R1}\sin\beta_1 + F_{R21}\sin\beta_2 = F_E\cos\beta_1, \tag{1}$$
$$m_1\ddot{y}_1 + k_1y_1 - k_{21}y_{21} - F_{R1}\cos\beta_1 + F_{R21}\cos\beta_2 = F_E\sin\beta_1, \tag{2}$$
$$m_2\ddot{x}_2 + k_{21}x_{21} - F_{R21}\sin\beta_2 = 0, \tag{3}$$
$$m_2\ddot{y}_2 + k_{21}y_{21} - F_{R21}\cos\beta_2 = 0. \tag{4}$$

Summing up the Eqs. (1) and (3), (2) and (4) as well as (3) and (4), the following equations can be formed:

$$m_1\ddot{x}_1 + k_1x_1 - F_{R1}\sin\beta_1 + m_2\ddot{x}_2 = F_E\cos\beta_1, \tag{5}$$
$$m_1\ddot{y}_1 + m_2\ddot{y}_2 + k_1y_1 - F_{R1}\cos\beta_1 = F_E\sin\beta_1, \tag{6}$$
$$(m_2\ddot{x}_2 + k_{21}x_{21})\cos\beta_2 + (m_2\ddot{y}_2 + k_{21}y_{21})\sin\beta_2 = 0. \tag{7}$$

Merging Eqs. (5) and (6), the equation can be formed as:

$$\frac{m_1\ddot{x}_1 + k_1x_1 + m_2\ddot{x}_2}{\sin\beta_1} + \frac{m_1\ddot{y}_1 + k_1y + m_2\ddot{y}_2}{\cos\beta_1} = F_E\frac{\cos\beta_1}{\sin\beta_1} + F_E\frac{\sin\beta_1}{\cos\beta_1}, \tag{8}$$

and after converting Eq. (8):

$$(m_1\ddot{x}_1 + m_2\ddot{x}_2 + k_1x_1)\cos\beta_1 - (m_1\ddot{y}_1 + m_2\ddot{y}_2 + k_1y_1)\sin\beta_1 = F_E. \tag{9}$$

Splitting up the motion of x_2 and y_2 into the components, the following form can be written:

$$(m_1\ddot{x}_1 + m_2\ddot{x}_1 + m_2\ddot{x}_{21} + k_1x_1)\cos\beta_1 - (m_1\ddot{y}_1 + m_2\ddot{y}_2 + m_2\ddot{y}_{21} + k_1y_1)\sin\beta_1 = F_E, \tag{10}$$

$$(m_2\ddot{x}_1 + m_2\ddot{x}_{21} + k_{21}x_{21})\cos\beta_2 + (m_2\ddot{y}_1 + m_2\ddot{y}_{21} + k_{21}y_{21})\sin\beta_2 = 0. \tag{11}$$

The levers guide the motion of each of the two masses between floor and mass m_1 and between mass m_1 and mass m_2. Therefore, the coordinate vectors with the characters x and y can be merged and replaced by character s.

Then the Eqs. (10) and (11) can be formed as:

$$m_1\ddot{s}_1\cos^2\beta_1 + m_2\ddot{s}_1\cos^2\beta_1 + m_2\ddot{s}_{21}\cos\beta_2\cos\beta_1 + k_1s_1\cos^2\beta_1 + m_1\ddot{s}_1\sin^2\beta_1$$
$$+m_2\ddot{s}_1\sin^2\beta_1 + +m_2\ddot{s}_{21}\sin\beta_2\sin\beta_1 + k_1s_1\sin^2\beta_1 = F_E, \tag{12}$$
$$m_2\ddot{s}_1\cos\beta_1\cos\beta_2 + m_2\ddot{s}_{21}\cos^2\beta_2 + k_{21}s_{21}\cos^2\beta_2 + m_1\ddot{s}_1\sin\beta_1\sin\beta_2$$
$$+m_2\ddot{s}_{21}\sin^2\beta_2 + k_{21}s_{21}\sin^2\beta_2 = 0, \tag{13}$$

with

$$s_{21} = s_2 - s_1. \tag{14}$$

After simplifying the Eqs. (12) and (13), the final equations of motion for the analyzed conveyor model are:

$$(m_1 + m_2)\ddot{s}_1 + m_2\ddot{s}_{21}(\cos\beta_2\cos\beta_1 + \sin\beta_2\sin\beta_1) + k_1s_1 = F_E, \tag{15}$$
$$m_1\ddot{s}_1(\cos\beta_2\cos\beta_1 + \sin\beta_2\sin\beta_1) + m_2\ddot{s}_{21} + k_{21}s_{21} = 0. \tag{16}$$

3. Results and discussions

The results of the above equations can be used to optimize the dynamic parameters.

3.1. Variation of the angles of the dynamic model

For the further analysis of the dynamic model, three cases are of particular interest:
– Case one with $\beta_1 = \beta_2$,
– Case two with $\beta_1 = 0$ and
– Case three with $\beta_2 = 0$.
For case one with $\beta_1 = \beta_2$, Eq. (15) can be converted step by step:

$$(m_1 + m_2)\ddot{s}_1 + m_2\ddot{s}_{21} + k_1s_1 = F_E, \tag{17}$$
$$m_1\ddot{s}_1 + m_2\ddot{s}_1 + m_2\ddot{s}_2 - m_2\ddot{s}_1 + k_1s_1 = F_E, \tag{18}$$
$$m_1\ddot{s}_1 + m_2\ddot{s}_2 + k_1s_1 = F_E, \tag{19}$$

to the final form:

$$m_1\ddot{s}_1 + k_1s_1 - k_{21}(s_2 - s_1) = F_E. \tag{20}$$

Eq. (16) is transformed by the same way into the final form:

$$m_2\ddot{s}_2 + k_{21}(s_2 - s_1) = 0. \tag{21}$$

For case two with $\beta_1 = 0$, the equations are:

$$(m_1 + m_2)\ddot{s}_1 + m_2\ddot{s}_{21}\cos\beta_2 + k_1s_1 = F_E, \tag{22}$$
$$m_2\ddot{s}_1\cos\beta_2 + m_2\ddot{s}_{21} + k_{21}s_{21} = 0. \tag{23}$$

For case three with $\beta_2 = 0$, the following equations can be formed:

$$(m_1 + m_2)\ddot{s}_1 + m_2\ddot{s}_{21}\cos\beta_1 + k_1s_1 = F_E, \tag{24}$$

$$m_2\ddot{s}_1\cos\beta_1 + m_2\ddot{s}_{21} + k_{21}s_{21} = 0. \tag{25}$$

3.2. Calculation of the displacement

To find the zero displacement s_{10} of mass m_1 and the maximum displacement s_{20}, of mass m_2, the corresponding equations for case $\beta_1 = \beta_2$ can be formed as:

$$s_{10} = \frac{(k_{21} - m_1\omega^2)F_{E0}}{(k_1 - m_1\omega^2)(k_{21} - m_2\omega^2) - k_{21}m_2\omega^2}, \tag{26}$$

$$s_{20} = \frac{k_{21}F_{E0}}{(k_1 - m_1\omega^2)(k_{21} - m_2\omega^2) - k_{21}m_2\omega^2}. \tag{27}$$

Eq. (26) can be adjusted in a way that s_{10} will become zero. For that case, the minimum transmission of forces to the floor is achieved [6, 7].

Based on this dynamical model, the minimum transmission of vibration and forces to the floor is achieved. As soon as mass m_1 remains stationary, the total excitation is passed over to the absorber mass m_2, supplying the optimum conveying of goods [8].

4. Conclusions

In this paper, a dynamic model of a two-mass linear vibratory conveyor, conducted with the calculation of kinematic parameters for the model is determined. The result of the elaboration is a mechanical model, which can be used as base for the modification of the conveyors motion and simultaneous the elimination of vibration forces to the floor of a building. The excitation of the system is transferred to an absorber mass, which represents the conveying element and a transfer of vibrations to the ground will not take place.

General equations for the model are developed and the final equations to calculate minimum and maximum displacements of the two masses are shown.

Based on the results of the paper, parameters for the design of two-mass linear vibratory conveyors can be defined and simulated.

Acknowledgement

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