Numerical Review of Selected Solutions of Vibratory Feeders Capable of Dosing Feed Material

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Abstract

The authors investigate selected solutions, to show how hard it is to find the ones that would simultaneously: dose the feed, work on a centrifugal drive, and could be freely scalable. Moreover, the authors introduce a classification of analysed cases by their amplitude-frequency characteristics. Exemplary characteristics of simplified models allow distinguishing which one of them is suitable to be adopted for dosing conveyor (feeder). The authors come to the conclusion that it is worth to begin the design process exactly by composing a proper mechanical system, in respect of amplitude-frequency characteristics. Furthermore, the paper points out the most important features of vibratory feeders, capable of dosing bulk materials.

Keywords: vibratory feeder, conveyor, continuous dosing. productivity control

1. Vibratory conveyor structure, application

Transporting machines, carrying bulk material that performs the oscillating movement, inclined by some angle in regard to conveying direction, where feed material performs the stepwise movement, are called ‘vibratory conveyors’ [1].

Materials can be transported by the angle from -15º to +15º, in a broad spectrum of productivity [2]. Conveyor’s troughs may be variously customized, for instance, sections may be closed, being dustproof, or laid with wear-resistant tiles, or built with appropriate steel suitable for the food industry.

Typical vibratory conveyor, driven by electrovibrators is shown in Fig. 1. The trough (1), elastically supported with suspension (2), excited to motion by a set of two counter-rotating, centrifugal electrovibrators (3) that in this case are subjected to self-synchronization in the plane of the drawing. The machine transports the feed (5) to the right.

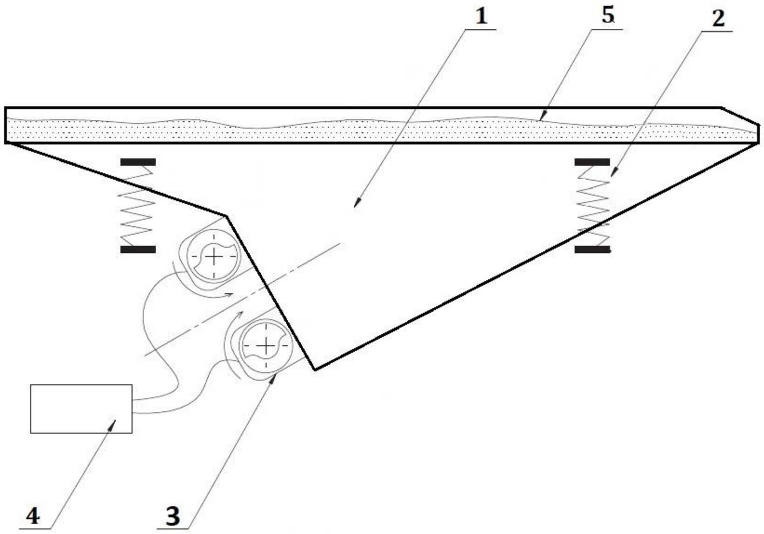

Figure 1. Classic one-mass vibratory feeder, dedicated for bulk materials

By the design side [3], in this type of devices, transport is performed with a velocity dependent on:

1) the excitement frequency, delivered by the control module (4) that results in the trough frequency
2) the harmonic force that results in the trough amplitude,
3) the trough inclination and characteristics of considered conveyor, under the feed load.

The productivity is then a parameter that the user is having a direct influence on. Manipulating productivity is often necessary for production lines. In particular, the complete stop of the transport is a special case that is often desired. However, in practice achieving it requires a high dynamic of the stop and resume. Conveyors capable of such work are called vibratory feeders, able of dosing feed materials.

2. Desired solutions

On today's market of vibratory feeders, there is a lack of solutions that would be simultaneously able to:

1) dose the feed material, allowing for smooth and dynamic regulation of productivity within 0-100%,
2) work on an inexpensive inertial drive (centrifugal),
3) could be freely scalable, so it would be possible to adopt them for any productivity.

In the current situation, relatively small feeders are widely encountered [4]. It is so, because machines of considerable dimensions have high inertia due to their mass.

Moreover, the kinetic energy of high-speed rotary vibrators prolongs the response time of the system [5].

In the third part of this paper, the authors show how difficult it is to find solutions that meet the listed criteria.

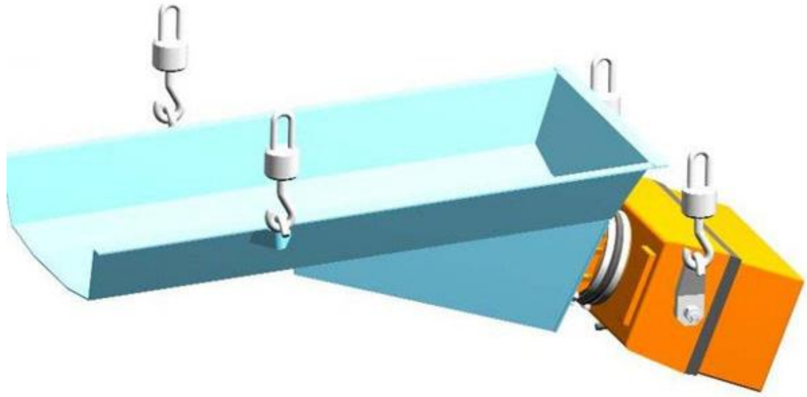

Figure 2. Dosing vibratory feeder, made by the Ofama company [6], equipped with electromagnetic drive, that dominates in such applications

3. Current solutions

Currently, only relatively small devices provide precise dosing (productivity up to 20 t/h). An example of such a device is shown in Fig. 3 [7]. It enables continuous control of the transportation velocity, but only within the half of its characteristic. Only the types equipped with the expensive electromagnetic drive (exemplary is shown in Fig. 2 [6]) are able to control productivity in the full range. Sizable feeders, capable of transporting over 1000 t/h can be set for certain productivity only during a full stop. Their transporting velocity is constant during operation, or slightly variable, like for instance in the Ofama solution [8]. Those types of conveyors do not allow for intermittent operation. Because of that, designers attempt to accomplish sudden stops by many other means.

For instance, in the Russian patent [9] there is a hopper equipped with a mechanical valve (Fig. 4). The device works like a regular conveyor. At first, feed material fills the trough’s hopper, and then it moves out of the trough by the outfall placed further. Whenever the level of the feed in the final container reaches 98% of the assumed capacity the device shuts the drive down. The machine reduces its oscillation frequency passing natural one during which amplitude rises, and phase difference increases. It leads to a temporary transport acceleration, even shaking the material out of the trough. Finally, the transport stops, and missing part of the assumed capacity is precisely dosed by the mechanical valve propelled with a pneumatic actuator. Such a solution requires an additional, controllable valve system. It makes the structure more complex that decreases its dependability and rises expenses. This kind of device is of low work culture because it causes unintentional strew of the material.

Figure 3. Vibratory feeder, proposed by TSN,
with productivity controllable from 5 to 10 t/h [7]

A good example of the transport stoppage by means of amplitude reduction, instead of the mechanical cut-off, is the Japanese patent [10] published in the year 2015. It postulates the conveyor harmonization in such manner, the working point and the point of transport stoppage are over-resonance frequencies. Thanks to that, such a mechanical system is able to reduce its transporting velocity smoothly and slowly, until complete stop, without the need for passing any resonance point. Thereupon, there is a slow productivity reduction, which does not allow for a dynamic stop, which is the crucial feature of a dosing feeder.

Published by the end of the year 2019 the Polish patent claims [11] postulate slowing down trough oscillations to significantly low frequency when transport does not occur anymore. Even so, the system passes its resonance zone, it is equipped with a dedicated damper, which reduces unwanted excitation at that zone. To some point, this method regulates feed material slowing down the process. The device gets characteristic, that enables to apply such machine as a dosing feeder, however, the durability of this system is dubious under numerous stops.

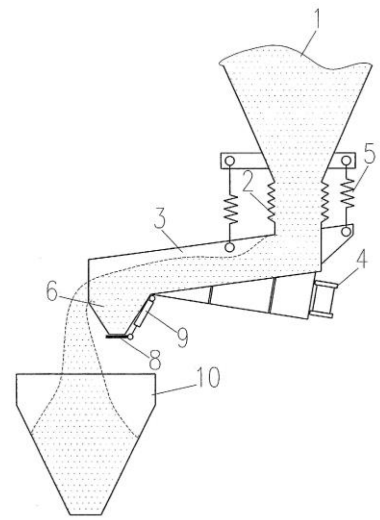

Figure 4. Russian vibratory feeder, with material cut-off by means of the mechanical valve [9]: 1 – hopper filled with medium, 2 – flange, 3 – trough, 4 – electrovibrator, 5 – suspension system, 6 – reservoir hopper, 8 – cut-off flap, 9 – actuator

Both solutions, Polish [11] and Japanese [10], assume excitement's frequency reduction, and also the amplitude, as a way for transport stoppage. When considering low excitation frequencies, it can lead to a step characteristic of the feed received. Also, the distance on the frequency characteristic, between the working point and the point of transport stoppage is considerable and influences time response. Moreover, manipulation of the productivity in sizable devices may be time-consuming, due to its inertia.

In authors' concepts (patent claims [12,13]), designers presume a dynamic elimination of forces exciting the trough. It dampens down oscillations that provoke transport. Solutions assume placing components' centres of gravities in common points, which are simultaneously laying in the excitement direction.

Such a mechanical system allows for the full productivity change, reducing the excitation frequency only by a dozen per cent. Furthermore, the transport stoppage occurs mostly as a result of the amplitude reduction, with still relatively high excitation frequency. That assures continuity in the feed outlet, even when the velocity is close to zero. Unlike previous solutions, with major frequency reduction, that leads to step characteristic of the outlet.

On the other hand, concepts like [12,13] imply the necessity of passing its first resonance frequency, when the complete stop of the whole machine is required. This, however, can be achieved when there is no more of feed material inside the trough.

4. Restraints of the current market

Solutions presented in section 3 allow presuming that any attempt of counteracting natural amplitude-frequency characteristics of the certain mechanical system are often either ineffective, low culture [9], or complicated [11]. Therefore, it is worth to look into characteristics of the conveyors. Figure 5 presents exemplary feeders' characteristics, where behaviour trends may be observed.

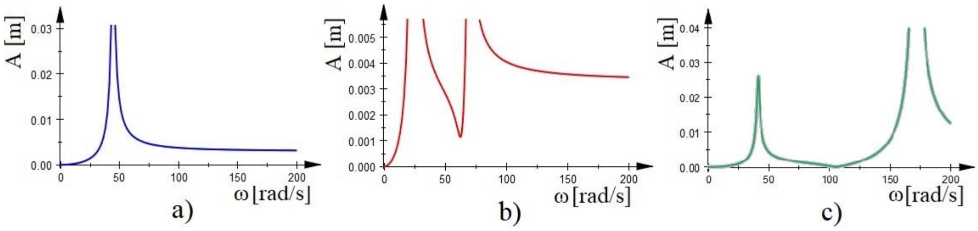

Figure 5. Exemplary characteristics of the feeder:
a) one-mass, with no additional insulation; b) two-mass, vibratory insulated by the frame; c) two-mass, with dynamic elimination [14]

A great majority of encountered conveyors can be represented by one of the above, exemplary characteristics. Such classification may be helpful, to distinguish which mechanical composition is suitable for the required purpose.

In the first case (Fig. 5(a)) to stop the transport completely, the considered conveyor has to slow down its angular velocity from the working point (where frequency and amplitude are sufficient – usually around 150 rad/s) to the limit point, where throw coefficient is 1 [15,16], what usually means the complete angular velocity reduction, through the natural frequency zone (except for the Polish patent [11]). Furthermore, this means passing through the resonance frequency where transport accelerates and conveyor itself has a tendency to stuck [17]. Because of those, machines of such characteristic are not well suitable for dynamic feeders.

Two-mass systems, exemplified by Fig. 5(b), are even more unsuitable for dosing purposes, for their working point is often behind two resonance zones. Thus, the full stop of the device requires passing both of them, which prolongs the stopping time, even more, while that should be possibly short. Even though there are satisfying vibroisolating properties [17,18], and low energy consumption, systems like those are not well applicable as dosing feeders.

Finally, the third characteristic – Fig. 5(c) is capable of changing its transport velocity in the complete spectrum, swiftly. Moreover, it is achieved with relatively little frequency reduction, and without the necessity of passing any resonance zones (in this case, working in between 100-150 rad/s is sufficient).

This kind of mechanical system composition eventually seems to be suitable for the needs of swift productivity manipulation.

5. Conclusions

Vibratory conveyors, regardless of their natural restraints, are applied as feeders, dosing bulk materials. Unfortunately, most encountered solutions are not very competitive because of their expensiveness, caused by a costly electromagnetic drive, or complicated and undependable build.

It is worth to begin the design process by composing a proper mechanical system, in respect of its amplitude-frequency characteristic. Often, the inappropriate approach is to counteract the natural behavior of the system. For instance, equipping suspension with dedicated dampers [11] or inefficiently cutting off the feed material [9].

Shaping proper frequency characteristic, at the stage of the designing process, seems to be the simplest, the most inexpensive, and the most effective way of building the vibratory conveyor capable of dosing. It should begin with the mechanical scheme, creating mathematical model and examining whether the obtained behavior meets the requirements. Bearing in mind that the most important features of vibratory dosing feeder are:

- the capability of dynamic productivity control (0-100%)
- proper amplitude-frequency characteristic
- simple composition
- high dependability
- inexpensive drive and control system (as the most costly part of the machine)
- being easy to scale

This attitude alongside with the strategy of controlling is presented in the consecutive paper by the present authors on the VIBSYS 2020 conference.

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