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Linear motion mechanisms in the transport of loose products in the food industry

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The dynamic growth of production, which characterizes the development of the modern food industry, requires systematic improvement of the level of organization and automation of production processes. This also applies to organizational processes and to the in-house transport system, which must ensure the continuity of raw material supply and collection of finished products. The system must be closely connected with the existing production and allow for quick reorganization of the technological process depending on the production needs. Regardless of the size of the plant and the size of production, the appropriate selection of transport equipment determines to a large extent the efficiency of production lines.

As a rule, food industry plants have high processing capacity. Productivity of food processing plants reaches even several dozen tons per hour. The specificity of material movement differs significantly from other industries. Raw materials and food products are often characterized by increased acidity or alkalinity. They are perishable materials. They require special attention during storage, technological operations and transport activities [1].

In the food industry, internal transport is of great importance. This is due to the intensive flow of products between individual workstations, often products in various forms, products sensitive to humidity, temperature changes, contamination and damage during transport [2, 3]. During transport of loose products there are unfavourable phenomena that cause damage to the transported product. The unfavourable phenomena occurring during transport are as follows: grinding the product, crushing, fractionation and micro-cracks.

As a result of technological progress and development, the amount of products destroyed during transport is systematically decreasing. Bearing in mind the type of transport, solutions are chosen which allow reducing the risk of product loss.

IN-HOUSE TRANSPORT MODES in the food industry

Depending on the method of energy transfer and momentum for the movement of the transported material in food processing plants, the in-house transport can be divided into (figure 1): manual transport, mechanical transport, pneumatic transport and hydraulic transport [4].

In the food industry, the choice and type of organization within the company is fundamentally influenced by the nature of the technological operation and the physical and chemical properties of the product transported. The methods of transport (of the same product) suitable for

KEY WORDS:
Transport of loose products, hygienization of equipment, conveyors, mechanisms

SŁOWA KLUCZOWE:
Transport produktów sypkich, higienizacja urządzeń, przenośniki, mechanizmy

SUMMARY:
In the food industry different ways and mechanisms of transport of loose products are used. The main factors influencing the correct choice of the transport method are: type of the product, direction and distance of the transport, efficiency of transport equipment, aesthetics of workmanship, market availability and ease of keeping the transport equipment clean. The most important criterion determining the choice of mean/method of transport is the type, or rather the physico-chemical characteristics, of the product to be transported. A major technological challenge in the food industry is the transport of delicate products, susceptible to mechanical damage. In the food industry there is a variety of delicate products, which can be damaged during transport. This makes it necessary to withdraw the raw material/semi-finished product from the process line. Nevertheless, micro-cracks are important from the point of view of durability and further processing of the raw material, which accelerate the destruction of the product in the subsequent stages of the technological process. Such products/raw materials include soft fruits, crisps and breakfast cereals. The technologist must therefore choose the most appropriate dosage of products in order to reduce the time of operation during which mechanical damage to the product may occur and to minimize the weight of waste. Production programmes are often changed and it is important that the transport equipment has the ability to quickly change over to a new type of product. The main aim of the article is to review the existing methods of transport of loose products (including delicate products) with an indication of the direction of research on improvement of hygienization of equipment while maintaining satisfactory efficiency of transport of delicate products.

STRESZCZENIE:
W przemyśle spożywczym stosowane są różne sposoby oraz mechanizmy transportu produktów sypkich. Głównymi czynnikami wpływającymi na prawidłowy dobór sposobu transportu są: rodzaj produktu, kierunek oraz odległość transportu, wydajność urządzeń transportowych, estetyka wykonania, dostępność na rynku oraz łatwość utrzymania w czystości urządzenia transportującego. Najważniejszym kryterium determinującym dobór urządzenia/metody transportu jest rodzaj, a właściwie cechy fizyko-chemiczne produktu, który jest transportowany. Dużym wyzwaniem technologicznym w przemyśle spożywczym jest transport produktów delikatnych, podatnych na uszkodzenia mechaniczne, których zniszczenie powoduje konieczność wycofania surowca/półproduktu z linii technologicznej. Niemniej istotne są mikropęknięcia, które przyspieszają niszczenie produktu w kolejnych etapach procesu technologicznego. Technolog musi zatem wybrać najbardziej odpowiedni sposób dozowania produktów, tak by ograniczyć czas operacji, podczas którego może nastąpić uszkodzenie mechaniczne produktu oraz zminimalizować masę odpadu. Programy produkcji są często zmieniane, dlatego ważne jest, aby urządzenie transportujące miało możliwość szybkiego przezbrojenia dla nowego rodzaju produktu.
Głównym celem artykułu jest przegląd istniejących sposobów transportu produktów sypkich (w tym produktów delikatnych) ze wskazaniem kierunku prowadzonych badań nad poprawieniem higienizacji urządzeń przy zachowaniu zadowalających wydajności transportu produktów delikatnych.

TYTUŁ:
Mechanizmy ruchu liniowego w transporcie produktów sypkich w przemyśle spożywczym

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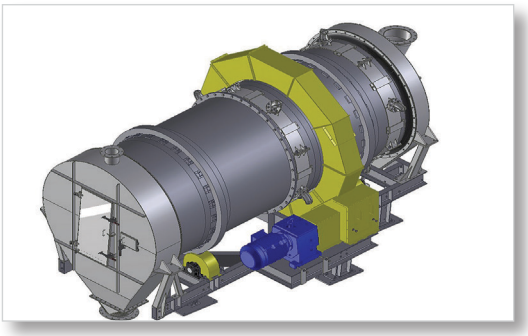

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- zbiorniki
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- stacje rozładunku big-bag
- myjki skrzyniopalet
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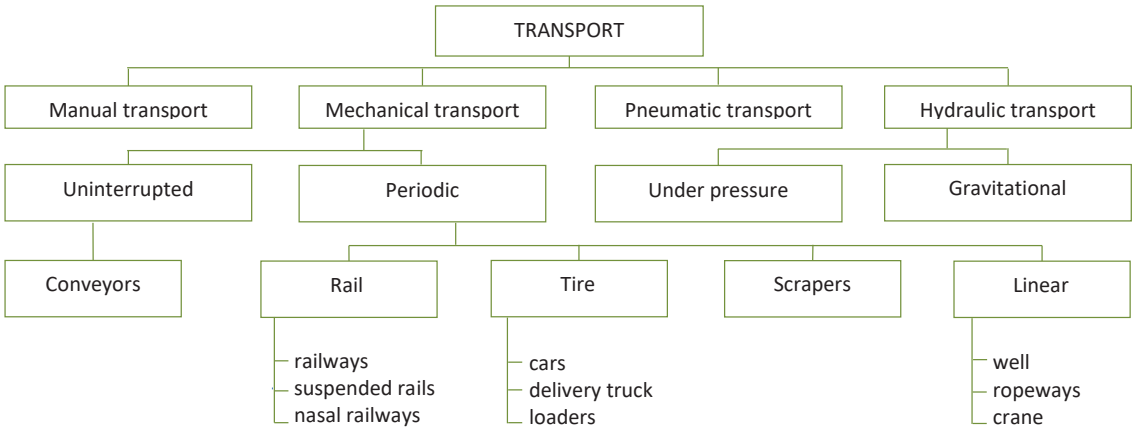

***Fig. 1** In-house transport modes [4]*

***Rys. 1** Rodzaje transportu wewnątrzzakładowego [4]*

plants with a single production system are different from those used for mass production. The material can be transported in different directions, e.g. horizontally, vertically and diagonally.

When designing transport systems for loose products, a solution for individual product features and technological process is selected. If there are small series of products with a large number of additives, it is still necessary to work manually. Along with the increase in efficiency, the transport of loose products is carried out by mechanical and pneumatic transport. In case of transport of solids we use hydraulic transport.

MECHANISMS for transporting loose products.

Due to the type of internal operations, two basic systems of mechanical transport solutions are used [5]:

- intermittent transport (in cargo units), where small loads are combined to form a pool (palletisation and containerisation) and moved by means of mechanised equipment operated by the operator,
- continuous transport, in which the movement of small loads or bulk materials takes place along specific routes without the participation of the operator.

The latter method is increasingly used in the food industry. This results in a higher form of organization and increased productivity due to the reduction of time during loading and unloading operations.

The capacity of a continuous conveyor Q is determined by multiplying the cross-section of the stream of the transported material on the load-bearing element A by the speed of movement of the material along the conveyor route v.

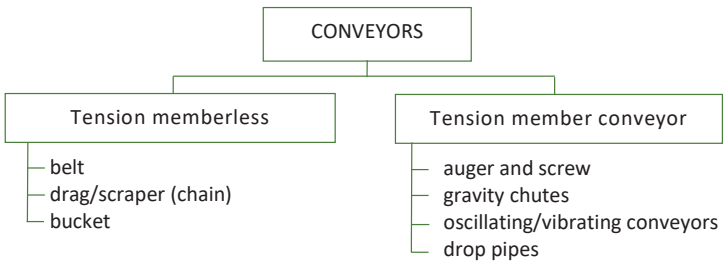

***Fig. 2** Dividing conveyors based on their moving elements [6,7]*

***Rys. 2** Podział przenośników w zależności od nośnika [6,7]*

$$Q = Av\frac{m^3}{s} \qquad \textbf{(rel. 1)}$$

On the basis of **relation 1** it can be stated that the transport capacity (volume flow) does not depend on the transport distance, provided that the feeding of the material is carried out continuously.

Continuous mechanical transport is achieved by the mechanisms (tension, pulse, shock, gravity) found in the conveying equipment (conveyors). Mechanical conveying devices used in granaries, mills, groats, feed factories, dairies, meat processing plants, monopoly plants, etc. can be divided depending on the type of carrier, i.e. the working element, which is the conveyor to (***figure 2***) [6, 7]:

A convenient frequently used criterion for dividing conveyors is the method of moving the material by the moving conveyor elements.

According to this criterion, a distinction is made between [8, 9]:

- transfer conveyors (moving floor conveyors) – conveyors in which the material rests motionless on the moving ground and together with this ground is transferred (e.g. belt conveyors),
- shifting conveyors (conveyors with stationary floor) – conveyors in which the material is loaded on a stationary floor and is moved over it (e.g. scraper conveyors).

TENSION memberless conveyors

Tension memberless conveyors form a group of conveyors used most frequently and to the widest extent. It is a device that moves materials transported in bulk or in the form of unit loads by means of a tension member, which is usually a closed circuit, which is the main driving element of the conveyor [5].

BELT CONVEYORS

Due to their many advantages, belt conveyors (***figure 3***) form the largest group of continuous conveying equipment. This position is due to their simplicity and construction features, which ensure high versatility of application. They are designed for horizontal transport or for various types of loose materials and unit loads, e.g. bags, boxes, etc. [11].

The operating principle of a belt conveyor is based on the endless rewinding of a flexible belt through return drums, at least one of which is driven. Along the conveyor

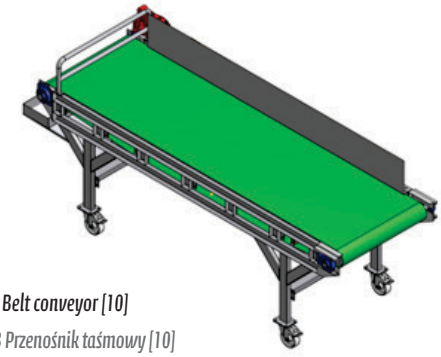

***Fig. 3** Belt conveyor [10]*

***Rys. 3** Przenośnik taśmowy [10]*

route, the belt is usually supported by roller sets, shaping the belt (on which the material is transported) in a flat or non-complex form [5]. This increases the cross-sectional area of the stream of the transported material and thus the conveyor's efficiency. Loading of the material on the belt conveyor, as well as unloading of the conveyor, can take place at any point of the belt. Belt conveyors are usually driven by electric motors. In order to ensure proper torque on the drive drum of the conveyor, the appropriate belt tension is necessary, which is achieved by means of load, screw or spring tensioners [11].

Belt conveyors in food industry are available in open and closed version. This type of transport equipment is very popular at high horizontal transport capacities of most food products such as cereals, crops, vegetables, fruits, etc. They are also suitable for brittle and delicate products, because during transport there is a minimal possibility of mechanical damage during contact between the product and the conveyor belt. In modern design of hygienic belt conveyors, the following EHEDG (European Hygienic Engineering & Design Group) guidelines are preferred [12]:

1. When transporting loose products it is recommended to use closed belt conveyors, which minimize the possibility of foreign bodies getting into the transported product.
2. Overloading of the conveyor belt must be prevented.
3. Avoid the risk of product contamination by accumulation of product on shafts and rollers.
4. Reduce the accumulation of dust under the conveyor belt, taking into account the closed conveyor belts.
5. Observe hygienic rules when transporting the product from the outlet of the conveyor belt to the inlet connecting the system components.
6. Use materials that are not susceptible to micro-cracks during prolonged operation. Cracks may cause the product to accumulate and then create possible contamination in the product being transported.
7. Access to cleaning and maintenance of machine elements should be provided, especially in closed conveyor belt systems.

In addition, individual technical solutions are applied, which introduce elements of technological innovation, which include [10]:

- modular construction,
- a wide range of belts adapted to the characteristics of the product,
- equipment including: scrapers, brushes, cleaning strips, chutes,
- height-adjustable conveyors,
- adjustable or fixed side stops,
- optical sensors, proximity sensors, cables and safety buttons,
- adjustable belt speed by means of a frequency converter,
- as well as equipping the conveyor with a drum motor in applications where there is no space for a geared motor.

Belt conveyors have many advantages, such as simplicity of manufacture and operation or versatility of use. Unfortunately, they have disadvantages, which are caused by process and constructional limitations:

- limited angle of inclination, depending on the size of the natural repose angle and the internal (intermolecular) and external (surface) friction coefficient of the transported material,
- limited durability and resistance of the belt,
- occurrence of dust during transport and transfer of products (inability to use, without appropriate housing and dust extraction system, for transport of dusty materials),
- lack of compliance with sanitary requirements imposed on food industry equipment (difficult access to cleaning),
- and the necessity of dedusting the place of charging and discharge from the conveyor.

In the food industry there is a variety of delicate products, which can be damaged during transport.

DRAG/SCRAPER (CHAIN) CONVEYORS

In a belt conveyor materials are transported along the route on the belt or on load-bearing elements of chain links, while in scraper conveyors (***figure 4***) are moved along the fixed surface of the channel by means of cross-bars or hooks placed on a single or double drawbar. The principle of operation of scraper conveyors is based on the mutual friction and abrasion of materials transported in bulk and a fixed casing. Therefore, the use of this type of equipment is limited only to certain types of dusty, granular and chunky materials, which are well flowing [5]. Conveyors are used in inter-operational and inter-departmental transport in cereal, feed, brewing and malt, fat, spirits, etc. They can have a closed tube [5]. They can have a tube closed or open from above [11].

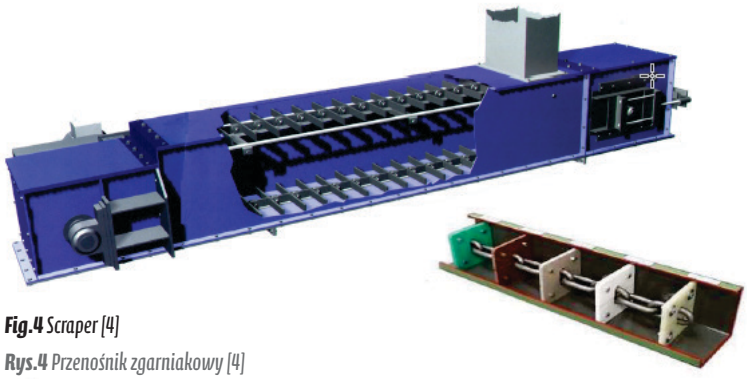

***Fig.4** Scraper [4]*

***Rys.4** Przenośnik zgarniakowy [4]*

According to the information from the European Group of Engineers of EHEDG, the design and operation of hygienic scraper conveyors is very difficult to implement. The use of such conveyors is only permitted in the absence of rigorous cleaning methods and the use of strong cleaning chemistry is acceptable. In the case of dry cleaning, chains and scrapers should be disassembled. Scraper conveyors are not recommended for food industry with higher standards of hygienic wet cleaning [12].

The advantages of the scraper (pick-up) conveyors are as follows:

- simple design and construction,
- possibility of loading and unloading in any horizontal section of the route,
- possibility of transporting dusty materials, harmful to the environment (due to the possibility of using a tight casing),

- very simple operation and easy maintenance of the device.

Defects of scraper conveyors include:

- unsuitability for transport of brittle, moist and sticky materials (there is crushing of the product and coating of scrapers),
- low movement speed,
- high consumption of the inner walls of the enclosure and chains,
- higher energy consumption than belt conveyors,
- limited scope of application (only products with specific granulation and difficulties in cleaning the conveyor),
- necessity of dedusting the place of charging and discharge from the conveyor.

The material can be transported in different directions, e.g. horizontally, vertically and diagonally.

BUCKET CONVEYORS

Bucket conveyors (***figure 5***) are used to transport bulk materials from one level to another (higher). This transport can be carried out on a vertical route, on a route inclined at a significant angle to the horizontal or on a circular route consisting of horizontal and vertical sections lying in one vertical plane. Unlike belt conveyors or scraper conveyors, the transport material does not form a continuous stream here, but is conveyed in suitable vessels, so-called buckets (buckets), attached to the pulley.

In straight bucket elevators, the load-bearing elements (buckets), fixed to a single or double belt or chain pulley, pass through the drum or through the sprockets mounted on the drive shaft at the top of the housing (head) and on the tension shaft at the foot of the housing. The entire transport mechanism is built into a tight casing. Feeding of the transported material takes place by taking buckets from the lower part of the casing or by filling the buckets with buckets from the filling opening. Pouring out, on the other hand, takes place in the upper part of the housing through an appropriate hole, under the influence of gravity (slow-running conveyors) or centrifugal force (high-speed conveyors) [5]. Such solutions are used in cereal, fruit and vegetable, potato, confectionery, spirits and fat industries. Bucket conveyors are used for transport of irregularly shaped, brittle and difficult to discharge materials (centrifugal conveyors) and for transport of fine-grained and loose materials (gravity conveyors) [11].

Fig. 5 *Bucket conveyor [4]*

Rys. 5 *Przenośnik kubełkowy [4]*

Referring to the opinion of EHEDG engineers, it is worth noting that bucket conveyors are able to gently transport fragile products with high efficiency. They are used for unloading tankers with wheat and soybeans. An important advantage of bucket conveyors is that the product is transported without changes in the grain structure. When designing a bucket conveyor, care must be taken to [12]:

- prevent buckets from overfilling with the product,
- avoid contamination of products with grease,
- ensure availability for maintenance and cleaning,
- reduce chain and bucket wear through proper handling,
- completely empty the bucket,
- make sure that the buckets are covered and there is no possibility of foreign bodies getting in,
- carry out a hygiene risk analysis at each design stage, taking into account the type of product being transported.

Continuous mechanical transport is achieved by the mechanisms (tension, pulse, shock, gravity) found in the conveying equipment (conveyors).

In addition to the standard version, special versions of bucket conveyors are also available, which are characterized by the following innovation elements [10]:

- special bucket design for draining potatoes and apples,
- possibility of working in water immersion and dry conditions,
- possibility to mount a washer at the end,
- can be used for transport from the canal from the water transport,
- no damage to the raw material,
- elimination of blows of portion ejection,
- profiled bottom,
- replaceable parts that wear out quickly.

In addition to the advantages of bucket-type transport solutions, attention should be paid to the limitations of these solutions due to their use:

- high mass of the structure,
- sensitivity to overload (it is important that the dosing to the conveyor is even),
- significant wear of load-bearing elements, especially when transporting highly abrasive materials,
- necessity of dedusting the place of loading and unloading surface.

TENSION MEMBER conveyors

Tension member conveyors are devices which continuously move materials transported in bulk or in the form of unit loads without the use of a tension member, but with the use of another element (e.g. a screw shaft), or by using the phenomenon of friction on the smooth surface, rotating shafts, pushing impulses, shocks or gravity. [5]

AUGER AND SCREW CONVEYORS

Screw conveyors (***figure 6***), also called screw conveyors, are used to transport loose, fine, dusty and fine-cut materials, mainly in the building materials industry, food, grain and mill industry, etc. They can move the material horizontally, at a certain angle and also vertically.

The basic elements of the conveyor structure are the trough and the screw. The trough can be of U-shaped or circular cross-section. Inside the trough there is a screw in the form of a shaft with a sheet metal strip wound on it along the screw line. The screw, by turning, moves the material in the trough in the direction of the outlet opening. The movement of the material in the conveyor takes place in a fixed trough and is forced by a rotating screw shaft. Depending on the type of transported material, several types of screw surfaces are used: solid, spiral, ribbon and vane. Screws with a solid surface are used to transfer non-sticky materials. Conveyors with a ribbon screw surface are used to transport materials in the form of large pieces and with a high tendency to clump together. On the other hand, conveyors with vane screws are used for conveying dough-like (sticky) materials [11]. Many researchers are concerned with the theoretical explanations and descriptions of the behaviour of a screw conveyor [14, 15].

Fig.6 *Auger and screw conveyor [10]*

Rys.6 *Przenośnik ślimakowy i spiralny [10]*

Spiral conveyors (***figure 6***) are often used instead of pneumatic systems. They are built of a pipe inside which a spiral is placed, which is driven from an electric motor by means of a gearbox.

The EHEDG group of engineers' recommendations for the design of hygienic auger and spiral conveyors are as follows [12]:

1. When transporting the product by means of trough screw conveyors, account should be taken of the possibility of easy and quick opening of the top covers for dry cleaning.
2. Use food-grade seals that are approved for contact with food.
3. It should be possible to open the side cover of the tubular screw conveyor to remove and clean the screw.
4. The strength of the flexible pipe for spiral conveyors should be high enough to withstand the friction of the spiral with the product being transported.
5. The spiral should always be made of stainless steel.
6. Spiral conveyors should be able to be completely disassembled for cleaning, especially the element connecting the spiral with the drive journal.
7. Use spiral conveyors for products that do not require transport and dry cleaning is sufficient.

In addition to the standard version of the screw conveyor, innovative and special versions according to the following list are also available [10]:

- certified for food use in stainless and acid-resistant versions,
- optional equipment: chutes, gate valves, assembly supports, inspection and cleaning manholes,
- working vertically, horizontally, at an angle,
- tubular, trough, wiping,
- shape and type of ribbon selected individually for a specific application,
- adjustable screw shaft speed by means of an inverter,
- equipped with a special shaft end for accurate dosing of products,
- distribution – transport of the product in two opposite directions at the same time,
- equipped with an additional heating or cooling jacket.

The main advantages of screw and auger conveyors are:

- simple construction,
- easy operation and maintenance,
- possibility of transport in different directions,
- possibility of using a screw conveyor as a mixing device,
- tightness, thanks to which it is possible to transport dusty and toxic products,
- quick cleanability,

The main drawbacks are:

- high energy consumption caused by the friction of the product against the surfaces of the screw and housing,
- difficulties in handling coarse-grained products,
- shredding of materials, especially brittle materials,
- significant wear to the screw surface and housing due to friction, especially when transporting hard and abrasive products,
- problem with centre bearing (sometimes blockages), especially when moving adhesive materials.

GRAVITY CHUTES AND DROP PIPES

Chutes (slides) are among the simplest devices for the transport of bulk materials and, in some cases, unit loads. These devices, in the form of an open or closed section chute (pipe), set at a significant angle to the level, are used for the free movement of materials under gravity [5].

The angle of inclination of the chute must be greater than the angle of friction of the material moving on this surface. The sliding speed of the load depends on the difference between the angle of inclination of the conveyor and the angle of friction. The sliding speed of the material should not exceed 2. In the case of large differences in levels, screw sliding conveyors are used, because straight conveyors (while maintaining the speed limit) would be too long. The material slides freely on the screw surface wound on the middle column. They are mainly used for handling unit loads, especially bags.

When designing gravity slides and drop pipes in the food industry, it is important to remember [12]:

1. The discharges, channels and pipes must be designed so that there is a continuous product flow.
2. The manifolds used should be easy to clean (e.g. in twisting and dead zones) and pay attention to the product's collection points, as they can cause contamination.
3. Vibrations or a hammer should be used to improve the flow in the product build-up points.
4. Gaskets should be perfectly matched to avoid product build-up.
5. The length of the slider (gutter) shall be so short as to control the flow of the product.
6. Open elements of sliding channels should be protected against the escape of dust and foreign bodies into the product.
7. Use hygienic valves that can be quickly dismantled and cleaned.

Advantages of gravity chutes and drop pipes:

- simple construction,
- absence of any moving parts,
- quick disassembly and reassembly,
- cheap operation – no energy costs,
- easy to maintain hygiene,
- and the minimum of mechanical transport of the product, and thus there is no possibility of damage to the product.

In addition to the advantages, there are also disadvantages, which are associated with the high cost of building rooms in a stacking system, the abrasive products chute abrasive products and the possibility of blockages in hygroscopic products.

Each transport should be approached individually and with great responsibility.

OSCILLATING CONVEYOR

Oscillating conveyors belong to the group of tensionless conveyors, in which loose materials move in the trough or in the pipe as a result of the use of their inertia. The troughs of these conveyors, by means of a vibration inducing drive, perform cyclic movements periodically with variable speed and variable acceleration. The material in the trough continuously makes short slides or jumps, moving in the direction of transport.

Conveyors whose cyclic movements are parallel to the trough surface are called oscillating conveyors, whereas conveyors whose direction of movement is inclined at a certain angle to the trough surface are called vibrating

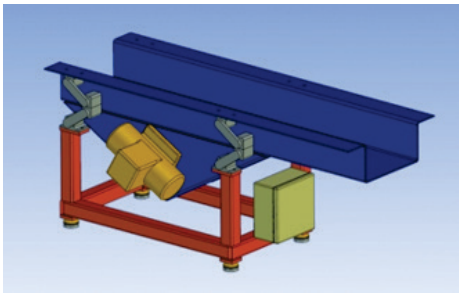

***Fig. 7** Vibrating conveyor [10]*

***Rys. 7** Przenośnik wibracyjny [10]*

conveyors. Another criterion for dividing conveyors into shaken and vibrating ones is the nature of the movement of the transported material. In shaken conveyors, the material slides in the trough under the influence of inertia forces, regardless of the direction of parallel or inclined motion, while in vibrating conveyors – the transported material usually makes micro jumps [5].

Vibrating conveyors differ from the oscillating conveyers with a different drive. The troughs of vibrating conveyors are introduced to vibrations by means of electromechanical, electromagnetic, hydraulic and pneumatic drive. The troughs of oscillating conveyors are introduced into a reciprocating motion by means of two crank mechanisms, crank-wagons, elliptical wheels, etc. Additionally, oscillating conveyors can be equipped with pneumatic or hydraulic drive, which will allow for regulation of the amplitude and frequency of trough movements depending on the required efficiency.

When designing and selecting hygienic oscillating conveyors, the following elements should be taken into account [12]:

1. Oscillating conveyors should be protected against the penetration of undesirable elements into the transported product.
2. Overloading of the vibrating chute must be prevented.
3. Oscillating conveyors act with little force on the product being transported, and thus it is possible to transport sensitive products.

The group of oscillating conveyors is characterized by many advantages to which they belong:

- simple construction and ease of use,
- possibility of full encapsulation of the process,
- possibility of performing various technological procedures during transport (e.g. drying, cooling, screening),
- low energy consumption and low trough consumption even when transporting highly abrasive products (this applies mainly to vibrating conveyors).

The disadvantages of oscillating conveyors include:

- significant drop in transport efficiency at an upward angle,
- unsuitability to transport very light and fragile products,
- noisy work,
- and the transmission of vibrations to the substructure and the ground.

CONCLUSION:

The biggest problem and challenge faced by technologists designing a new plant or modernization is to perform the operation according to high standards of technology and hygiene at the right time and place. Selection of appropriate means of transport in the food industry (e.g. conveyors) requires proper analysis of the transported product and taking into account the following parameters:

- the capacity of the conveyor,
- physical properties of the transported material,
- indication of the place, direction and route of transport,
- granularity of the product and the possibility of mechanical damage during transport,
- costs of transport, purchase and operation of the conveyor,
- EX zones for explosive dusts.

There are no typical and standard solutions, so it is difficult to prefer a universal conveyor that will work with every product. Each transport should be approached individually and with great responsibility. The most important thing is to choose the right type of transport for a given technological process. Recently, with the increase in sanitary requirements and technical culture, some developmental tendencies in the construction of conveyors in the food industry have been observed.

Users pay attention to ergonomic design, aesthetic execution, reliability, low energy demand, high safety standards, full automation, reduction of losses in the transported raw material and enabling encapsulation of the process.

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