Study of operating parameters of a plate conveyor used in the food industry

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Abstract. Internal transport (means of continuous transport) is an inseparable element of technological processes in the food industry. The selection of appropriate parameters of the transport equipment depends on the product being manufactured, its design features, packaging and transport conditions. The paper presents the characteristics of a plate conveyor, selection of operating parameters in the juice transport process in a glass bottle. The paper presents selected test results depending on the linear speed of the plate conveyor, the angle of inclination of the load mass transport module and the position of the gravity centre. The work defined the linear speed ranges of the conveyor and the angle of inclination of the conveyor transporting module for transported glass bottles filled with juice.

1. Introduction

A proper choice of technological and organisational parameters of production processes enables more efficient and effective production of goods [1]. Traditionally, research on manufacturing processes was mainly conducted to improve efficiency and accuracy, as well as to lower costs [2]. Production operations within an automated production line would be impossible if they did not cooperate with means of continuous transport and robots. Robots replace human employees in harmful working environments, where highly qualified personnel is scarce [3]. Robots have become a common solution in a wide range of industrial processes and have therefore contributed to boosting efficiency and flexibility of production, increasing work safety, allowing to achieve high quality of production at higher reliability and lower cost [4]. Whether or not a production process to be executed is capable of achieving the assumed performance parameters depends, among others, on reliability of machines and technological devices that make up the system under design [5].

There are various methods of transport systems used in the food industry. Usually, fluid products are transported by different pumping systems [6], solid and powder by different type of conveyors. Operation time of machine components is strongly affected by resistance to different types of wear likewise sliding, abrasive, corrosive, particle erosion or even cavitation wear [7]. Thus, to prevent damage of transportation system, it is crucial to use proper material, or to adjust accurate operating parameters that prevents from wear.

Transport works play an important role in the warehouse systems and logistics of manufacturing systems, as well as distribution [8, 9, 10, 11]. Conveyors are counted among the means of continuous transport; whose task is to regularly feed and receive the transported cargo. Depending on the
construction, they are used to transport unit loads, as well as loose materials carried in bulk. Commonly used are belt conveyors mounted in a transport system, consisting of conveyor modules with and without drive, turntables or arches. In [12] a construction of a belt conveyor was proposed, enabling the drive of straight sections and curves with one drive. Support and drive elements are subjected to variable loads resulting from the possibility of transporting loads of various shapes and weights on one conveyor [13]. In order to increase reliability of conveyors, models describing the dynamic impact load processes [14] have been developed, the aim of which is to create a mathematical description of the conveyor operation under varying loading conditions.

To assess the value of operating conditions, a number of approaches is used, due to the fact that in practice there are different circumstances allowing (or not) the use of certain methods [15]. The additional operating conditions of conveyors are normative requirements related to the reduction of noise and vibrations [16, 17]. In [18], algorithms and design procedures are described, as well as ways to control the assembled transport system in terms of eliminating bottlenecks causing queues at junction points. The problem of selection of the kinematic structure of sorting devices cooperating with the conveyor is described in [19]. The goal was to determine efficiency of the overload conveyor work on the conveyor from the weight of the loaded elements. In addition, the technical conditions of the sorting process on the conveyor and at buffer points were described on the basis of characteristic features recognised by scanning and detection system. In order to increase efficiency of transport, as well as correct localisation and tracking of carried goods, UHF-RFID technology is being used more and more often [20]. Identification results enable on-line efficiency analysis and are used to quickly identify a specific item in a transport system.

Plate conveyors are included in the group of wire conveyors. The load-bearing elements of plate conveyors are train chains, usually two-legged, connected to each other by plates, on which the transported material is moved. These conveyors are often used for transporting glass packaging. They can be used not only as transport means, but also as buffering conveyors or cooperating with additional technological devices for filling, labelling, closing, capping, sorting, etc. Plate conveyors are often used where high temperature or chemical resistance is required.

The paper presents the characteristics of a plate conveyor PP-4/2014, selection of operating parameters in the juice transport process in a glass bottle. The goal was to identify variables that affect work efficiency when transporting glass packaging. The article describes regression models used to identify basic technical parameters of transfer points in operational conditions. The highlighted parameters are conveyor efficiency, unit load of the conveyor belt and the possibility of queuing. The test results are to be the basis for formulating the requirements for the use of this type of conveyor on the production line. The requirements should relate to reliability and efficiency, correctness of construction and the possibility of incorporating the conveyor into the production system.

2. Methodology, test stand and material

The conveyor as a mechatronic device consists of a physical mechanical model, a motion device (motor + gearbox) and a controller that controls the movement of the motor and the conveyor itself [21]. The research on determining transport efficiency of glass packaging has been carried out on the PP-4/2014 plate conveyor (Figure 1).

The metrological values were measured using:

- ArcoMaster electronic protractor with a spirit level,
- electronic calliper,
- AXIS BA30C platform scale.

The conveyor is driven by an electric motor type SK1SI40-IEC80-80S/4 TF from “NordDrivesystems” with a capacity of 0.55kW and a rated voltage of 380V. Using a control and measurement system consisting of an iG5A inverter, the engine speed and controller with display have been adjusted. Liquid crystal, which is equipped with time measurement (Figure 2).
Transport efficiency tests were conducted for piece cargo (a glass bottle with juice of 0.33 litre capacity) - Table 1, with three angles of inclination of the transport module 0°, 3° and 6°. During measurements, the following values were recorded: frequency of the inverter, linear speed of the conveyor belt, rotational speed of the drive motor of the conveyor belt, loading time, general transport time, distance between loads.

| Weight (kg) | Height (mm) | The diameter of the package (mm) | Contact area (mm) |
|------------|-------------|---------------------------------|------------------|
| 0.16       | 165         | 30                              | 22.76            |

Figure 1. Plate conveyor – general view and bottle transport.

Figure 2. Measurement controller and inverter.
3. Results and discussion

Tables 2-4 present the results of transport conditions tests on a plate conveyor for glass bottles.

**Table 2.** The results of measurements of transporting glass bottles at the angle of inclination of the transporting module is equal to 0°.

| No. | Frequency of the inverter (Hz) | Loading time (s) | General transport time (s) | Distance between loads (m) | Conveyor speed (m/s) | Conveyor speed (rpm) |
|-----|-------------------------------|------------------|---------------------------|---------------------------|----------------------|----------------------|
| 1   | 10                            | 1.2              | 16.5                      | 0.25                      | 0.281                | 39                   |
| 2   | 11                            | 1.2              | 16.5                      | 0.27                      | 0.31                 | 43                   |
| 3   | 12                            | 1.1              | 15.3                      | 0.28                      | 0.34                 | 47                   |
| 4   | 13                            | 1.0              | 14.7                      | 0.3                       | 0.37                 | 51                   |
| 5   | 14                            | 1.0              | 14.4                      | 0.32                      | 0.4                  | 55                   |
| 6   | 15                            | 0.9              | 13.0                      | 0.32                      | 0.43                 | 60                   |
| 7   | 16                            | 0.9              | 13.3                      | 0.4                       | 0.46                 | 64                   |

**Table 3.** The results of measurements of transporting glass bottles at the angle of inclination of the transporting module is equal to 3°.

| No. | Frequency of the inverter (Hz) | Loading time (s) | General transport time (s) | Distance between loads (m) | Conveyor speed (m/s) | Conveyor speed (rpm) |
|-----|-------------------------------|------------------|---------------------------|---------------------------|----------------------|----------------------|
| 1   | 10                            | 1.1              | 16.8                      | 0.25                      | 0.281                | 39                   |
| 2   | 11                            | 1.1              | 17.0                      | 0.27                      | 0.31                 | 43                   |
| 3   | 12                            | 1.1              | 16.1                      | 0.30                      | 0.34                 | 47                   |
| 4   | 13                            | 1.1              | 15.8                      | 0.30                      | 0.37                 | 51                   |
| 5   | 14                            | 1.0              | 15.2                      | 0.33                      | 0.40                 | 55                   |
| 6   | 15                            | 1.0              | 15.1                      | 0.40                      | 0.43                 | 60                   |
| 7   | 16                            | 1.0              | 14.2                      | 0.42                      | 0.46                 | 64                   |

**Table 4.** The results of measurements of transporting glass bottles at the angle of inclination of the transporting module is equal to 6°.

| No. | Frequency of the inverter (Hz) | Loading time (s) | General transport time (s) | Distance between loads (m) | Conveyor speed (m/s) | Conveyor speed (rpm) |
|-----|-------------------------------|------------------|---------------------------|---------------------------|----------------------|----------------------|
| 1   | 10                            | 1.1              | 18.4                      | 0.23                      | 0.281                | 39                   |
| 2   | 11                            | 1.1              | 17.8                      | 0.25                      | 0.31                 | 43                   |
| 3   | 12                            | 1.1              | 17.0                      | 0.30                      | 0.34                 | 47                   |
| 4   | 13                            | 1.1              | 17.1                      | 0.34                      | 0.37                 | 51                   |
| 5   | 14                            | 1.1              | 16.5                      | 0.37                      | 0.40                 | 55                   |
| 6   | 15                            | 1.1              | 16.7                      | 0.42                      | 0.43                 | 60                   |
| 7   | 16                            | 1.1              | 16.5                      | 0.50                      | 0.46                 | 64                   |

Based on the results of the tests, the conveyor efficiency $Q$ was calculated (1):

$$Q = G \frac{v}{a}$$  \hspace{1cm} (1)

where:

$G$ – unit weight of the load (kg),
$v$ – linear speed of the conveyor belt (m/s),
$a$ – distance between loads (m).
Figures 3 - 6 show the results of calculations of conveyor efficiency at three values of the conveyor transport module inclination angle and the variable frequency settings of the inverter.

**Figure 3.** Graph of conveyor operation efficiency depending on the frequency of the inverter and the angle of inclination of the conveyor transport module.

**Figure 4.** The dependence of efficiency on the speed of the conveyor transporting the glass bottles at an angle of 0°.

**Figure 5.** The dependence of efficiency on the speed of the conveyor transporting the glass bottles at an angle of 3°.
Figure 6. The dependence of efficiency on the speed of the conveyor transporting the glass bottles at an angle of 6°.

Figure 7. A comparison of the conveyor efficiency results for all tested transport module angles.

Analysing the above graphs, their course for glass bottles retains repeatability for the inclination angle of the 0° and 3° transport module. In both graphs, the extreme is located in the speed range from 0.37 m/s to 0.43 m/s. The curve at an angle of 6° has a stable drop without sudden fluctuations, except for 0.31 m/s where a slight increase in performance is observed.

4. Conclusions

Conclusions regarding correctness of the transport process:

- During transportation of glass bottles, a slip was observed between the conveyor plate and the load contact surface. This phenomenon intensified with the increase of the speed of the transport device. Slip occurred mainly when placing bottles on the conveyor belt. This phenomenon is caused by the difference in velocity vectors and the direction of the bottle being put on the tape and the speed of the belt movement. It is also important to locate the centre of gravity of the packaging and shape of its bottom.

- Based on the conducted tests, it was noticed that with the increase of the inclination angle of the transport module, efficiency of the device decreases. The most noticeable is the angle of inclination of the transport module of 6°. The area between 3 and 6 degrees is interesting, which would have to be investigated, because in this range there was the greatest reduction in the efficiency of the plate conveyor.
Conclusions regarding the construction of the conveyor:

- Efficiency measurements were carried out in laboratory conditions, but the results obtained can be approximated and used in industrial applications [22, 23].
- In order to increase work efficiency while increasing the conveyor speed and elevation angle:
  - use overlays on the conveyor plates, whose task is to increase the coefficient of friction between the bottle base and the plate surface [24, 25].
  - do not use rubber aprons on the side surface of the conveyor side. As previous studies have shown, rubber aprons pressing the bottle from both sides cause an increase in resistance when moving the bottle and as a result the bottles fall over [25, 26].
- One way to increase efficiency when moving bottles at an angle greater than 3o and when increasing speed is to build a grip conveyor into the production line. Details of this solution are presented in the paper [26].

Conclusions regarding the use of the conveyor in the technological line:

- The feeder is not an isolated element but is a part of the transport system. The work efficiency of the conveyor is to be correlated with efficiency of loading, receiving and additional devices, e.g. control devices, labelling machines. For this reason, subsequent research should focus on reliability of the conveyor, including temporary booking. Mathematical analysis is performed using Markov processes considering the states of work, renewal and standstill [27, 28, 29].
- Another analysis that should be carried out in relation to the considered conveyor as a part of the production line is the analysis of operational reliability by calculating the value of the OEE (Overall Equipment Effectiveness) indicator. The OEE indicator is the basis for setting the direction of activities to improve production processes. It enables to identify bottlenecks, as well as technical and organisational problems of the enterprise. OEE is also a measure of implemented improvements and allows you to calculate the benefits of improving processes and eliminating individual problems [30, 31 32, 33].

5. References

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