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Design of a pipe conveyor drive in the context of reducing its vibrations

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Abstract:
This study analyzes the largest drive unit for a pipe belt conveyor in terms of its impact on reliability, maintenance, and performance. It compares the connection of the drive drum shaft to a gearbox and an indirect connection by an intermediate member in the form of a belt drive, taking into account their advantages and disadvantages in various applications. It evaluates that the memory drive can effectively dampen vibrations, which is especially important in the operation of conveyor belts, where vibrations are frequent and can cause the need and breakdowns. In addition, belt drives simply require less regular maintenance and can improve the reliability of the entire system. Based on this issue, the selection of the optimal drive unit for the selected application is presented.

Key words:
pipe belt conveyor, drive unit, belt transmission, vibrations

Introduction

In recent years, conveyor belts have been among the most widely used means of transport in various industries. As a result, they develop very quickly in terms of design (especially about their performance) and find possibilities of use in a wide variety of operating conditions, especially in the continuous transport of bulk materials. The advantages of belt conveyors compared to other means of transport, especially in terms of performance, economy of operation and maintenance, are increasing (Marasová et al., 2006).

Nowadays, there is an increasing emphasis on minimizing vibration and noise caused by the operation of machinery and equipment, as these factors pose a potential environmental and safety problem. Vibration can negatively affect the functionality of mechanical systems and the safety of operation by reducing their reliability and service life. There are a number of factors that contribute to vibration in machine designs, including imbalance, misalignment, mechanical wear of bearings, structural resonance, bent shafts, and excessive bearing wear (Moravič, 2018).

1 Methods and methodology

1.1 Pipe Belt Conveyor

A pipe conveyor has similar basic elements as a classic belt conveyor. Its construction is shown in Figure 1. It differs only in the structure of the supporting structure and the shape of the roller stool, which in classic belt conveyors forms the conveyor belt in the shape of a trough, while in the case of pipe conveyors, the annular roller stool forms the conveyor belt in the shape of a pipe (Marasová et al., 2002).

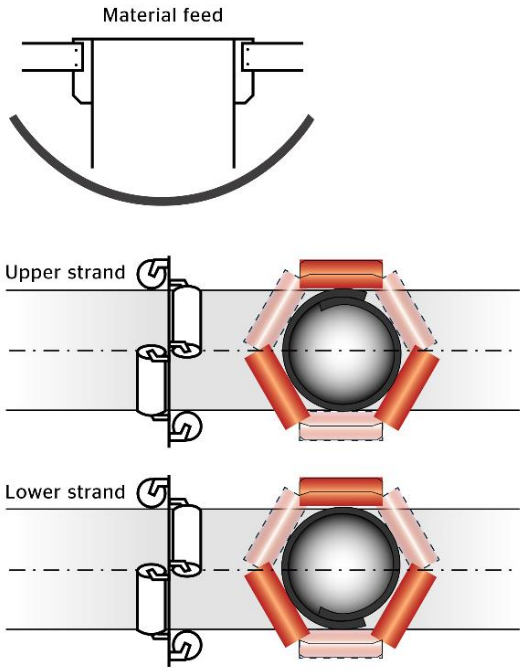

Fig. 1 *Schematic representation of the working principle of a pipe conveyor*
Source: Continental AG, 2017

Figure 2 describes the basic stages of the pipe conveyor's work.

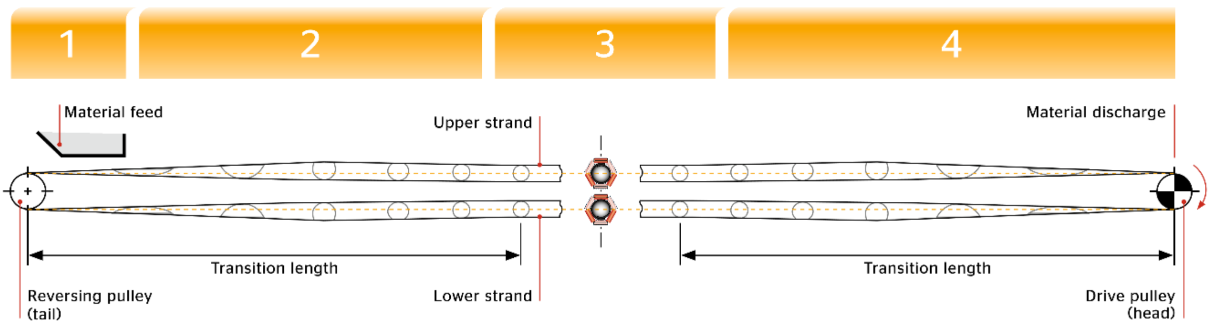

Fig. 2 *Stages of work of a pipe conveyor with positions*
Source: Continental AG, 2017

1) Material loading stage: At this stage, the material is loaded onto a pipe conveyor belt, which is shaped like a trough. Loading is carried out similarly to a conventional gutter belt.

2) Belt forming stage: After the material is loaded, the belt is gradually formed into a pipe shape by annular roller stools. This process allows the belt to take the necessary shape to transport the material.

3) Material Conveying Stage: Other annular roller stools are positioned along the entire length of the route and ensure a closed belt shape when transferring material. This means that the pipe conveyor belt isolates the material being transported and separates it from the surrounding environment.

4) Material unloading stage: At the end of the route, in front of the drive drum, the closed belt shape is opened by special rollers, and adopts first the trough, and then the straight shape on the drum. This process allows the transported material to be unloaded in the same way as with conventional belt conveyors.

1.2 Basic Structural Elements of Pipe Belt Conveyor

The basic structural elements of the pipe belt conveyor are shown in Figure 3, and we divide them as:

1) a load-bearing structure consisting of a metal structure and support plates on which annular roller tables are attached,

2) the upper branch of the conveyor belt, which carries the material and is still full,

3) the lower branch of the conveyor belt is empty in most cases, but it can also be used to transport material when using a loop,

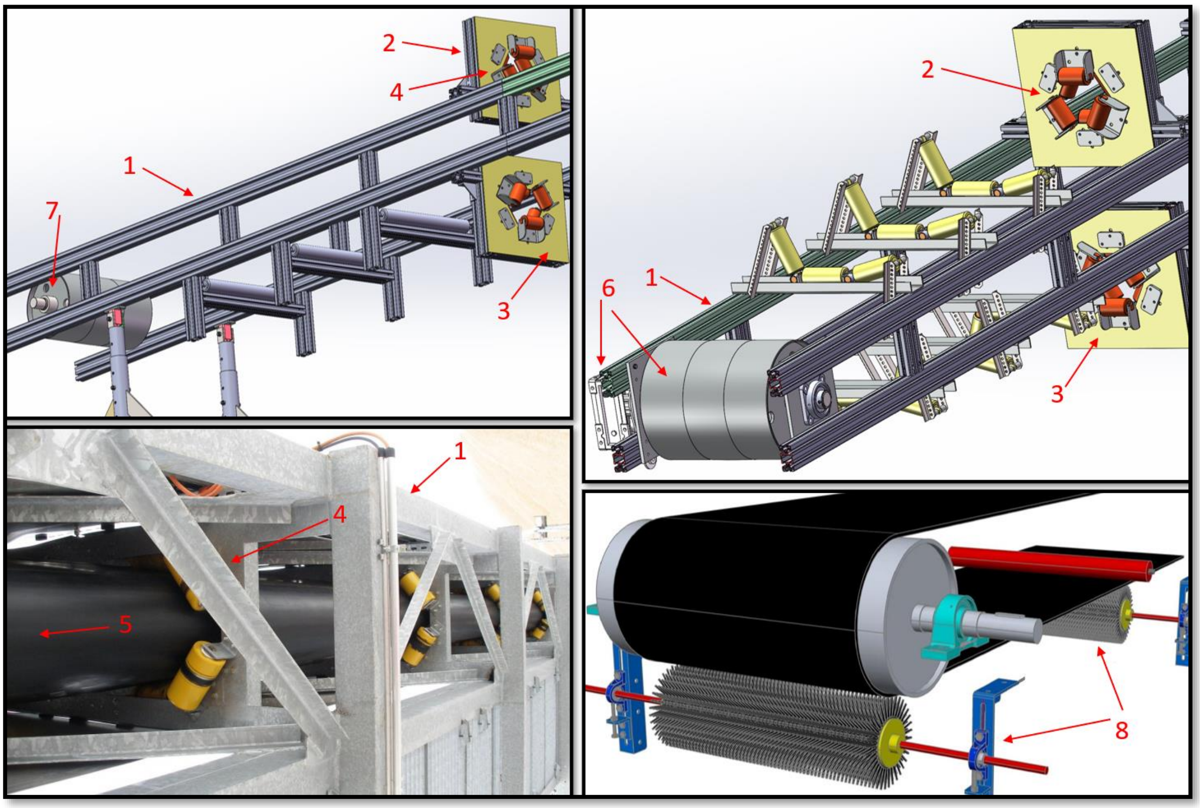

Fig. 3 *Basic structural elements of a pipe belt conveyor with marked positions*

4) annular roller stool, most often it consists of six rollers arranged in the shape of a ring, with three rollers on one side of the support plate and three rollers on the other side of the carrier plate, to prevent the conveyor belt from opening at the point of overlapping the edges of the belt,

5) Pipe belt conveyor requires special belts, which must meet demanding operating requirements. These pipe conveyors must have a flexible belt that allows for small-radius arcs, be able to form a closed pipe using annular roller stools, and be resistant to heat and friction with the rollers.

6) a drive station consisting of an electric motor, couplings, gearbox, and drive drum,

7) the return station consists of a tensioning device and a driven drum,

8) additional equipment such as cleaners, hoppers, dumps, chutes, belt scales, iron separators and others (Marasová et al., 2006).

1.3 Conveyor belt drive

The purpose of the drive is to generate a pulling force on the drive drum in order to ensure a certain speed of the conveyor belt with the transported load, both at the moment of starting the conveyor and in stationary mode. The most reliable and structurally simplest for general purpose belt conveyors and especially for the chemical, and food industries is the single drum belt conveyor drive.

The drive of the conveyor belt (Figure 4) consists of an electric motor, a gearbox, a drive drum, and flexible couplings. The belt is driven by friction between it and the drive drum. Normally, the drive is installed on the supporting structure of the conveyor (Marasová et al., 2006).

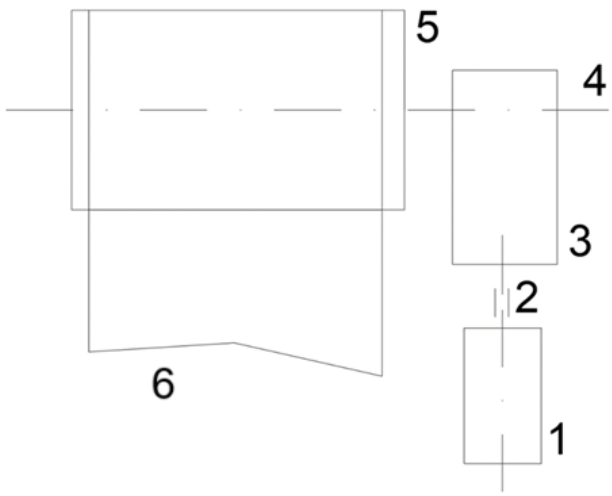

Fig. 4 *Conveyor belt drive diagram: 1 – electric motor, 2 – couling, 3 – gearbox, 4 – drive drum shaft, 5 – drive drum, 6 – conveyor belt*

2 Results

2.1 Pipe Belt Conveyor Input Data

The performance of a pipe conveyor depends on the total motion resistance, which is equal to the total circumferential driving force. Total motion resistance F_U (given in N) of the upper and lower arms of the pipe conveyor is determined on the basis of the calculation of partial resistances, whereby:

$$F_U = F_H + F_V + F_P \ , \tag{1}$$

where: F_H *– primary resistance,*
F_V *– secondary resistance,*
F_P *– slope and special resistance.*

Required mechanical power P_A (given in kW) on the drive drum of the pipe conveyor:

$$P_A = \frac{F_U \cdot v}{1000} \ , \tag{2}$$

where: v *– conveyor belt speed.*

Table 1 contains the input values for the calculation of partial resistances.

***Tab. 1** Part of the input values for the calculation of total motion resistance*

Parameter	Value
b_n [m]	0.25
B [m]	0.4
f [–]	0.04
H [m]	0
L [m]	9.5
Q $[\mathrm{t \cdot h^{-1}}]$	10.35
m_1 $[\mathrm{kg \cdot m^{-1}}]$	2.39
m_{kp} $[\mathrm{kg \cdot m^{-2}}]$	0.61
m_{rd} [kg]	3.45
m_{rh} [kg]	0.8
n_b [–]	1
n_d [kg]	1
n_h [–]	6
s_v [m]	0.0045
t_d [m]	3
t_h [m]	0.85
v_0 $[\mathrm{m \cdot s^{-1}}]$	0
v $[\mathrm{m \cdot s^{-1}}]$	1.2
μ_1 [–]	0.3
μ_2 [–]	0.3
ρ_s $[\mathrm{kg \cdot m^{-3}}]$	500

Based on the input values from Table 1 and using the methodology according to the authors Ambriško and Marasová (2023) and Marasová et al (2002), the result is Table 2.

Tab. 2 *Calculated individual resistors and mechanical power*

Parameter	Value
F_H [N]	542.66
F_V [N]	2253.53
F_P [N]	0
F_U [N]	2796.19
P_A [kW]	3.36

2.2 Choosing the suitable drive unit

Figure 4 shows a view of the current state of the drive of the test model of the experimental pipeline conveyor line.

The drive unit of the conveyor consists of an electric motor with an output of $P = 1.1$ kW, a gearbox with a gear ratio of $i = 40$, and a connection directly to the drive drum shaft. When comparing the power of the electric motor used with the calculated power required for the experimental line, we found that it was insufficient, which is one of the main reasons for the design of the new drive.

We made the choice of electric motor from the catalog of the manufacturer CHIARAVALLI, because we have good experience in testing the current condition of the pipeline conveyor. According to the calculated value of the mechanical power P_A for the new drive, we chose the CHT 112 M4/B14 electric motor with an output of $P = 4$ kW, and a speed of $n = 1400$ min^{-1}, and a CHO82 112B5/B14 gearbox with a gear ratio of $i = 40$.

Another point of the design of the new drive is the addition of a flexible element between the gearbox shaft and the drive drum. As a flexible element, we decided to use a belt gear, with the help of which we can also adjust the gear ratio of the drive to suit the required belt speed.

For our drive unit, we chose a V-belts system type VB (DIN 2215) consisting of 5 pieces with dimensions of 10 x 1900 from the manufacturer Optibelt. As a result, we have a new drive design diagram, which is shown in Figure 5.

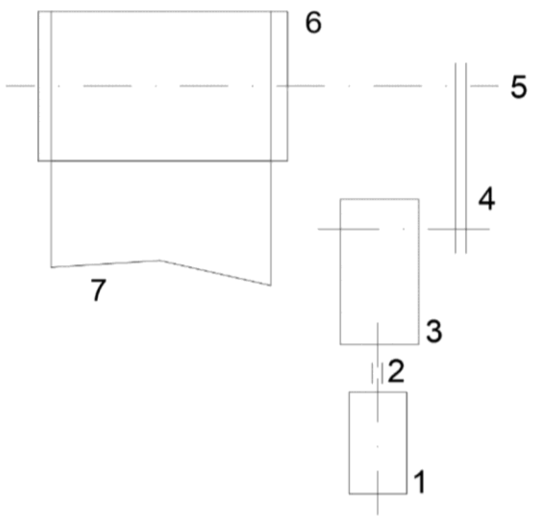

Fig. 5 *Diagram of the new pipe belt conveyor drive solution: 1 – electric motor, 2 – coupling, 3 – gearbox, 4 – belt transmission, 5 – drive drum shaft, 6 – drive drum, 7 – conveyor belt*

3 Conclusions

First, we calculated the required power of the pipe belt conveyor to ensure its proper operation. We found that the power required was significantly different from that of the original power unit. The power of the original unit was 1.1 kW, while the calculated power was 3.36 kW. This difference led to the decision to choose a new electric motor with a nominal power of 4 kW and the same type of gearbox. Another point of the design of the new power unit was the elimination of vibrations, misalignment of the shaft connection. When deciding between different types of gear units, it was essential to weigh their advantages and disadvantages with regard to the specific requirements and conditions of the application. In our case, we decided to use a belt transmission. A belt drive offers us the ability to effectively dampen vibrations. This factor is crucial, especially when operating a conveyor belt, where vibration is common and can lead to more wear and tear and machine failures. The reduction of vibrations in the conveyor drive has a positive effect not only on the drive itself, but also on other components and equipment in the vicinity. Vibration suppression means less stress on structural joints and bearings, which leads to an extension of their service life and thus a reduction in the number of failures. In addition, the belt drive is easier to maintain compared to other drive systems. It tends to wear less and requires less regular maintenance. From practice, we can say that belt transmission allows you to save time and maintenance costs, and at the same time reduce the risk of unplanned downtime in operation. This was followed by adapting the belt gear ratio to the speed requirement of the conveyor belt. And as a result, we have a belt transmission quickly, which is not a common habit, but it meets our requirements. If there is a need to change the gear ratio, this can be done easily and cheaply by replacing the pulleys. And since we take into account the fact that we use a frequency converter to control the electric motor, then we can only achieve a lower belt speed by changing the settings of the frequency converter, which can also achieve a more gentle operation of the entire mechanism. As a result, we have a new drive that can produce the required power for the pipe belt conveyor of the experimental line and eliminate the resulting vibrations.

In the next phase of the design, a detailed dynamic calculation will be implemented. We will also focus on vibration measurement for comparison with the original configuration. In some places, vibration measurements have already taken place in the original configuration of the drive, as reported in the article by Moravič and Kubala (2024).

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