Determination of resistance to motion during operation of belt conveyor

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Abstract: *Belt conveyors play a significant role in the transport of bulk materials due to a number of advantages such as: high capacity, economy, safety and reliability. The belt conveyor for bulk materials was observed in this paper. In order to drive the belt conveyor, the power of the driving electric motor must overcome all the resistances that occur during the transport of materials. The paper presents one of the possible approaches to the method of calculation and selection of belt conveyor parameters. The conveyor travel path was adopted, all resistances to the motion of the belt and materials were defined and the calculation of the total resistance to motion on characteristic transport sections was performed. The influence of conveyor loading and discharge devices, drive mechanism, way of moving the belt over the rollers were taken into account. The general calculation algorithm is presented and a graphical representation of the conveyor assemblies is given for the defined transport route.*

***Keywords**: BELT CONVEYOR, BULK MATERIALS, RESISTANCE, 3D MODEL*

1. Introduction

Belt conveyors are most commonly used conveyors for material handling. This paper considers a belt conveyor for handling bulk materials which are stored in heaps. The belt conveyor handles materials such as: minerals (ores, coals), earthly materials (gravel, sand, clay), processed materials (cement, salt, chemicals), agricultural products (grain, sugar, flour) and other similar powdery, granular or lumpy materials. Regarding the handling of bulk materials, their major features are: lump-size, bulk weight, specific weight, moisture content, mobility of its particles, angles of repose, abrasiveness, temperature, proneness to explosion, stickiness, corrosivity and hygroscopic properties [1].

Although the belt conveyors have been used for many years, there are still some problems in exploitation to be solved [2]. The companies that use the belt conveyors demand that they have high performance and high reliability. This may be achieved in the design phase, using mathematical models and simulations, which can have significant effect on reliability and exploitation of the belt conveyors. The mathematical model that provides the analysis of the belt conveyor dynamics was presented in [2].

Design of the belt conveyors meets many challenges. Mechanical components, such as idlers, drives, pulleys and many accessories are constantly developed to improve the performance and durability of the belt conveyor. Compared to other means of transport, belt conveyors demand low labour and energy consumption.

In [3], the analysis of force ratios of conveyor belt was conducted based on the formed geometrical model with application of FE analyses. Calculations, selection and modelling of the main elements of the belt conveyors were performed in [4, 5].

The method of measuring the resistances to motion of a single three-roller idler set with the use of a specially designed measuring stand was presented in [6]. Measurements performed in mine conditions provided the records of the real forces that exert load on the tested measuring set determination of the motion resistances of the set. This has enabled the analysis of the effect of belt conveyor design parameters on its resistances to motion.

2. Calculation

In order to commence the design stage of the belt conveyors, it is necessary to estimate the characteristics of the material which will be transported by that conveyor. In this study, coal was the material to be transported by the belt conveyor. The following initial data were taken into account: transport capacity, route scheme, characteristics of the transported material, mode of operation, and operating conditions.

The belt conveyors with rubber belt are the basic means for continuous transport of the bulk materials. The belt conveyors can practically be designed for any desired travel path. Their use is limited by the strength of belt, angle of incline or decline, and available space.

The successful design of the belt conveyor depends on both the characteristics of the material being transported and the behaviour of the materials on a moving belt. The optimal acceptable speed for transporting a specific material was chosen. In addition, the carrying and return idlers designs were adopted. The calculations of the belt, belt tension and motor drive power were conducted. All influential factors in the calculation are listed in the appropriate formulas. The methodology of calculation of the supporting structure is stated, as well as of the drive and of the return pulley.

During the design process, it is very important to properly determine the cross-sectional area of the material on the belt and, consequently, the calculation capacity of the belt conveyor. Also, it is important to optimally define the belt width and operating speed. The cross-sectional area of the material on the belt depends on the shape of the belt, namely on the adopted type of roller assembly and on the belt width. In addition, the real cross-sectional area of the bulk material on the belt depends on the way of dosing the material on the belt.

In order to determine the operating width of the belt (in meters) depending on its full width (B), the following expression is used:

$$b = 0{,}9 \cdot B - 0{,}05. \tag{1}$$

Geometrical parameters of the rollers were determined depending on the adopted type of roller assembly and the calculation of the cross-sectional area of the material on the belt was conducted.

Based on the required transport capacity, the belt width was determined according to the cross-sectional area of the material on the belt, operating speed and the bulk mass. The check was performed in relation to the size of the pieces of transported material. Necessary belt width was calculated based on (2):

$$B = 1{,}1 \cdot \left(\sqrt{\frac{Q}{v \cdot \rho \cdot k \cdot k_\beta}} + 0{,}05 \right) \tag{2}$$

where:

Q – is required capacity,
v – is transport speed,
ρ – is bulk density of the material,
k – is the coefficient that depends on the angle of pouring the material on the belt,
k_β – is the reduction coefficient that depends on inclination angle of the conveyor regarding the horizontal.

When defining the operating speed, some advice must be taken into account. It is often suggested to reduce the width of the belt and increase its speed accordingly. Increasing the speed causes a reduction in the drive load and tensile forces, which can result in the reduction of the weight of the conveyor and the reduction of the cost of transport. On the other hand, the question arises as to the justification of higher speeds with regard to the technical and exploitation conditions of the conveyor operation. It has been established that, for higher speeds and small belt widths, its motion is sometimes unstable, with more intensive spillage of the material from the conveyor, but also with the increased wear of the belt and the bearings.

In order to drive a belt conveyor, the power of the drive motor must overcome all the resistances that occur during transport from:

– lifting of the material,
– friction in carrying roller bearings on loaded (working) and unladed (non-working) parts,
– friction in bearings of the drive, tension, deflection and bending drum,
– bending of the belt,
– unloading - loading devices and
– resistance to the motion of the belt over the rollers.

The belt conveyor design meets the two basic problems: necessity to provide a drive with enough power to start the conveyor even under adverse conditions and to ensure that the maximum force acting on the conveyor is within safe limits.

Traction force calculation can be performed using an orientation or detailed procedure. Recently, many theoretical and experimental tests have been performed with the aim of more accurate calculations of resistance forces. The conveyor contouring procedure is used to determine the traction force. It consists of numbering the characteristic points of the closed contour of the conveyor in the direction of motion of the traction element, starting from the point with the least tensile force. The tensile force at each subsequent point is equal to the tensile force at the previous point increased by the magnitude of the resistance force between those points:

(3)
$$F_{(i+1)} = F_i + W_{i+(i+1)}$$

where:

F_i, $F_{(i+1)}$ – are the tensile forces in subsequent contour points *(i)* and *(i+1)*,

$W_{i+(i+1)}$ – is resistance force between the points *(i)* and *(i+1)*.

The calculation includes determination of the values of each resistance, taking into account the known technical-exploitation parameters of the conveyor. For example, expression for resistances on a rectilinear loaded working section of the conveyor is in the form presented by [4]:

(4)
$$W_P^{RO} = \omega \cdot g \cdot \left[(q_M + q_{VE}) \cdot L_h^{RO} + q_r^R \cdot L^{RO}\right] \pm (q_M + q_{VE}) \cdot g \cdot H^{RO}$$

where:

ω - is the coefficient of resistance to motion of belt across the carrying roller
q_M - is specific mass of transported material,
q_{VE} - is specific mass of the tractive element of conveyor,
L_h^{RO} - is the length of horizontal projection of the loaded working section,
L^{RO} - is the length of loaded working section,
H^{RO} - is the height of vertical projection of loaded working section.

Minimum belt tension in the upper branch of the conveyor is also verified according to condition of computationally permissible deflection of the belt in that part of the conveyor.

To ensure normal belt operating conditions, the drive drum must be selected correctly. Here, the following factors must be taken into account: the belt thickness and its bending stresses during crossing over drum, mean pressure between drum and belt, type and place of conveyor installation.

Minimal drum diameter is adopted depending on the number of belt layers, while the drum length was chosen in accordance with the adopted transport belt width. The adopted diameter of the drive drum must meet the following condition:

(5)
$$p_{sr} = \frac{F_o}{\mu} \cdot \frac{360}{\pi \cdot D \cdot B \cdot \alpha} \leq p_{doz}$$

where:

p_{sr} – is mean pressure between the drum and the belt,
F_o - is the traction force,
B – is the belt width,
D – is the diameter of the drive drum,
α – is the span angle,
μ – is the coefficient of friction between the drum and the belt,
p_{doz} – is allowable pressure between the drum and the belt.

The roller assembly is one of the most important elements on which the efficiency of the belt conveyor depends, and especially the life of the belt. The important requirements for idlers are proper support and protection for the belt and proper support for the material being conveyed. The design of the roller assembly mostly determines the size and character of the loads on the belt and rollers. It must be sufficiently strong and durable and must have as little mass as possible.

The following effects were taken into account during selection of the roller type: the load factor (which is proportional to the roller load and depends on the assembly type, bulk material mass, assembly step), the factor of operating conditions (which encompasses the character of conveyor design and the way of operation), the speed factor and influence of conveyed material.

The concept of calculations was based on DIN 22101 and FEM 2.124 standards [7-8].

The major steps in belt conveyor calculation were:

– definition of capacity of the conveyor,
– calculation of maximum belt tension required to convey the load,
– selection of belt,
– selection of drive pulley,
– determination of motor power,
– selection of idlers and their spacing.

The main technical parameters of the belt conveyor are: the capacity of transport, Q=230 t/h, the belt width, B=800 mm, and the belt velocity, v=1.6 m/s.

3. Design of the 3D model

Calculation of the belt conveyor has provided all data and dimensions of the belt conveyor elements. Subsequently, the modelling of elements and final assembly of the belt conveyor were conducted [5]. Designed 3D model of the belt conveyor was created using “Autodesk Inventor” software [9].

The model was created bearing in mind the order of the elements assembly into the final device. Most of the adopted elements (conveyor rollers, drive and tensioning device, bearings) are mounted on the carrying structure of the belt conveyor.

Appearance of the drive unit and the part of the carrying structure are shown in Fig 1.

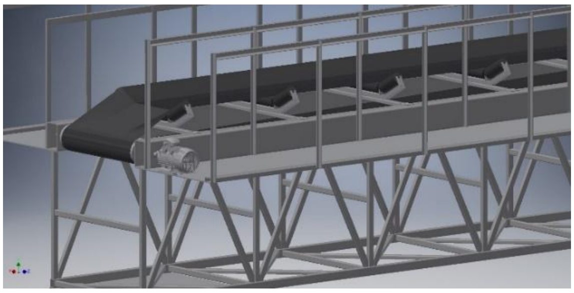

Fig. 1 *Drive unit with carrying structure of the belt conveyor*

Fig 2 presents the selected conveyor belt design. The tension pulley is located at the end of the belt conveyor.

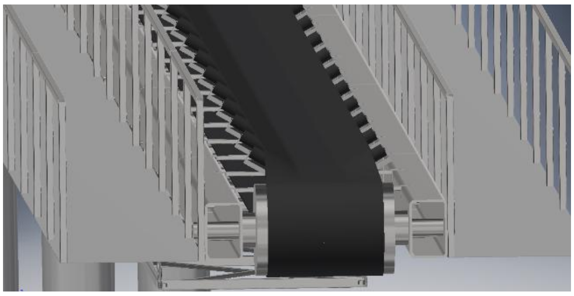

Fig. 2 *Conveyor belt design.*

Assembly with three carrying rollers was adopted in the paper. By reducing the length of the middle roller, it is generally possible to increase the lifetime of its bearings. However, due to need for unification and due to exploitation conditions, preference is given to roller assemblies with rollers of the same length. Thus, this solution was adopted in the paper (see Fig 3). Roller assemblies on the operating branch of the conveyor are presented in Fig 3.

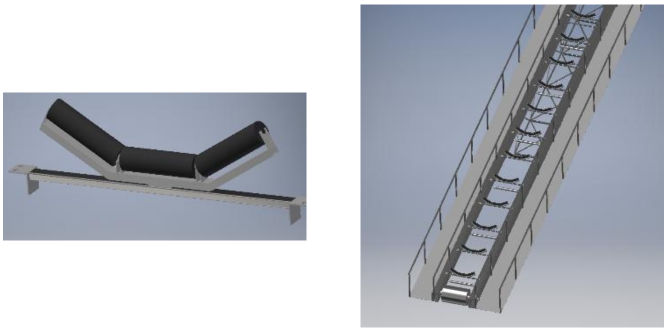

Fig. 3 *Belt conveyor rollers (left) and basic carrying structure on the operating branch of the conveyor (right).*

The overall model of the belt conveyor for continuous transport of bulk materials was obtained after all elements were assembled, and the result is shown in Fig 4.

Fig. 4 *Overall model of the belt conveyor.*

4. Conclusions

The belt conveyor is one of the most efficient conveyers. It is known as very configurable and easy to install.

The detailed calculation of the belt conveyor for conveying coal was conducted according to the design requirements and given transport capacity. The constant value of the tensile belt force during operation of the conveyor was used as foundation for calculations.

The conveyor dimensions obtained by calculations were used in 3D modelling of the conveyor. The used spatial modules of the software program have enabled the detailed analysis of deformations and stresses of the carrying structure of the designed belt conveyor.

To improve the design, the possible directions may include the creation of additional modules for research of the effects of variable belt tensile force and predicting the lifetime of the belts.

5. References

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