PRESENT THEORETICAL ASPECTS, TESTS AND PROPOSALS FOR FLOW CALCULATION ON ROLLER HORIZONTAL BELT CONVEYORS

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Abstract: *The paper contains a theoretical analysis and a series of experiments on the factors that the performance of the horizontal belt conveyors depend on, as well as experimentally verified suggestions for improving the performance of these machines.*

Keywords: *belt, seating, conveyor, inclination*

1. INTRODUCTION

Roller-based belt conveyors for granular and powder materials are used in all fields and rank first in terms of frequency of use, compared to other types of conveyors. For this reason, when the term conveyor is used without any other mention, its implied meaning is that of roller belt. This type of conveyor is the main means of conveyance, most commonly used in all fields of activity, and is superseded by other types of transportation devices only for inclinations of over 18 ° ... 22 °. Using them becomes economical if the minimum flow rate is at least 100 ... 300 t/h and the operation time is at least 5000 hours/year.

It is not recommended to use this type of conveyor for transporting large grain rocks and soft materials that tend to stick to the belt surface.

This is why, for the transport of ore, slanted belt conveyors are used on a lower scale; the horizontal plane transportation is preferred, provided that the ore pieces are not too large.

Thus, in the case of a 800 ... 1600 mm wide belt, it is recommended that size of the ore pieces should not exceed 150 ... 300 mm. If the pieces of ore are larger, intense wear will affect the belt.

2. THE STRUCTURE OF ROLLER BELT CONVEYORS

Belt conveyors are built basically in the same way, whether the flexible part is made of textile insert rubber, steel or gauze wire. Since textile insert rubber belt conveyors are the most frequently used, we will first consider the structure of this type of conveyors and then we will point out how certain execution details differ when the belt is made of metal. The main subassemblies of a roller flat belt conveyor, in the simplest form, are shown in Figure 1.

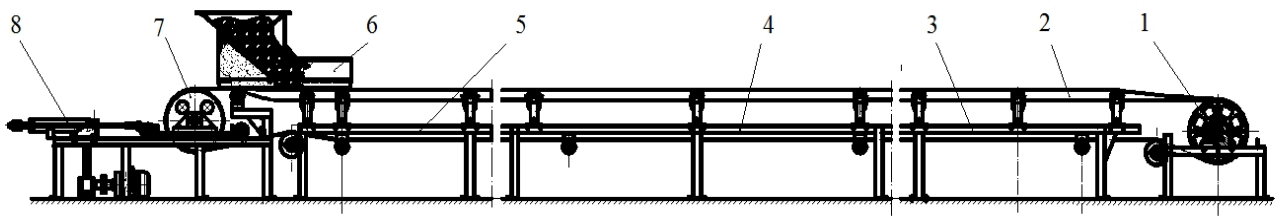

Fig. 1. Belt Conveyor Drawing
1 – motorized head pulley; **2** - belt; **3** - motor head support; **4** – intermediate frame; **5** - return end frame; **6** – loading device; **7** - return roller; **8** - tension device

3. FLOW RATE CALCULATION OF A HORIZONTAL ROLLER BELT CONVEYOR

On this type of belt the material being transported could be, theoretically, loaded up to the edge of the belt so that the section view will show an equilateral triangle (see the dashed line shown in Figure 2) where the angle between the slanted sides and the horizontal side is equal to the angle of repose in motion ρ_m. There is, in this case, the possibility for the material to flow over the edge of the belt, which is why, in the actual practice, the material can only be loaded on a length equal to $0,8 \cdot B$ and in such a quantity that the section resulted will correspond to the hatched triangle shown in Figure 2, whose sides are slanted against the horizontal plane by the angle:

$$\rho_1 = 0,5 \cdot \rho_m$$

or (if the angle of repose at rest is not known) approximately:

$$\rho_1 = 0,35 \cdot \rho$$

$$\rho_1 = 0,35 \cdot 26,8 = 9,38^0$$

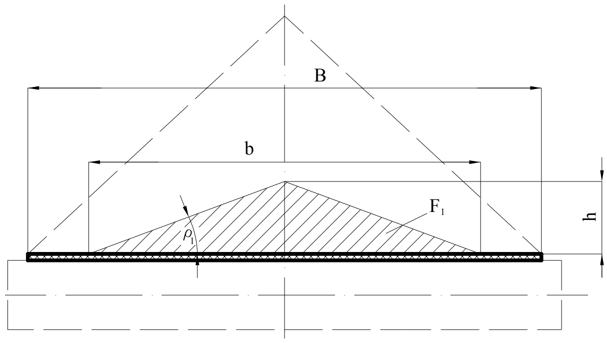

Fig. 2. Flat belt loading

The values of ρ and ρ_m angles are given in Table 1. For sand, the material that will be used in the experiments, the angle of repose at rest, determined experimentally at section 5.1 (Determining the characteristics of the material used for experiments) is 26.8 °.

Since the angle of repose in motion could not be determined experimentally, the following equation will be used in order to determine its value:

$$0{,}35 \cdot \rho = 0{,}5 \cdot \rho_m$$

based on the relations used for ρ_1, defined above.

Result:

$$\rho_m = \frac{0{,}35}{0{,}5}\rho = \frac{0{,}35}{0{,}5} \cdot 26{,}8 = 18{,}76^0$$

Aria triangular section of the layer of material:

$$b = 0{,}8 \cdot B$$

and $$h = 0{,}5 \cdot b \cdot tg\rho_1 = 0{,}4 \cdot B \cdot tg\rho_1$$

it is: $$A = \frac{b \cdot h}{2} = 0{,}16 \cdot B^2 \cdot tg\rho_1 \quad \text{m}^2$$

Table 1

Material	*Volumetric Weight γ t/m^3*	*Angle of Repose*		*Coefficient of friction at rest*		
		ρ	*ρ_m*	*steel*	*wood*	*rubber*
Sand	1,60...1,80	26,8°	18,76°	0,56...1	0,7	-

The weight of the material placed on a linear meter of belt:

$$q = A \cdot 1 \cdot \gamma = 0{,}16 \cdot B^2 \cdot \gamma \cdot tg\rho_1 \quad \text{t/m} \qquad (1)$$

$$q = 160 \cdot B^2 \cdot \gamma \cdot tg\rho_1 \quad \text{kg/m} \qquad (2)$$

where:

γ = the volumetric weight of the material, given in t/m^3

$\gamma = 1{,}60...1{,}80$ t/m^3

The result of the determinations was:

$\gamma = 1{,}536$ t/m^3 = kg/m^3

B = the belt width of the installation on which the experiments are performed, given in m;

$B = 0{,}2$ m

The productivity (flow) of a flat belt conveyor is determined based on the relation:

$$Q = 3{,}6 \cdot q \cdot v = 576 \cdot B^2 \cdot \gamma \cdot v \cdot tg\rho_1 \quad \text{t/h} \qquad (3)$$

Replacing all the values in the relation (3), there results:

$$Q = 576 \cdot 0{,}2^2 \cdot 1{,}536 \cdot 0{,}1652 \cdot v \quad \text{t/h}$$

$$Q = 5{,}846 \cdot v \quad \text{t/h} \qquad (4)$$

where: v = the speed of the belt, given in m/s

4. DESCRIPTION OF THE CONVEYING SYSTEM USED IN THE EXPERIMENTS

For experimental purposes there is used a belt conveying system as presented schematically in Figure 3. This system can both incline at an angle between 0° and 45° against the horizontal plane and work at varying belt speeds between 0 and 1 m/sec [1]. The experimental system is equipped with all the elements of a flexible traction industrial conveying system, the most important of which are specified in Figure 3.

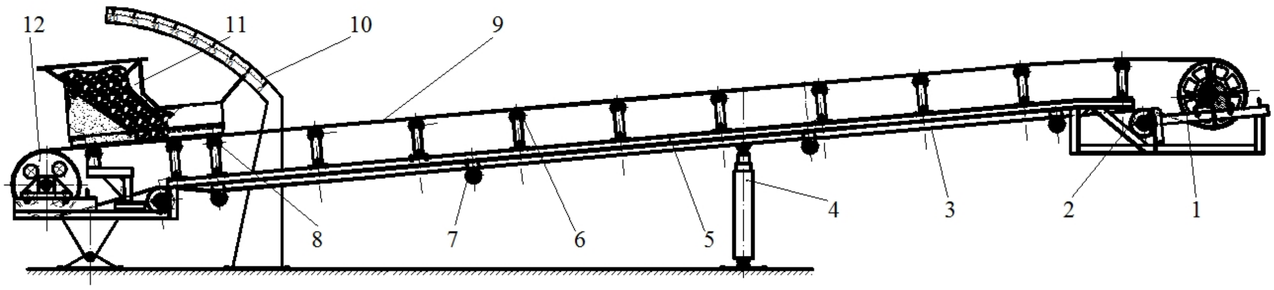

Fig. 3. Drawing of the installation required for experiments
1 – drive drum; **2** – actuating roll; **3** - the lower branch of the belt; **4** - lifting device; **5** – conveyor's bed; **6** – idle roller supporting the upper branch of the belt; **7 –** idle roller supporting the lower branch of the belt; **8** – roller bed; **9** - the upper branch of the belt; **10** - graduated sector; **11** - feeding device; **12** - Return drum.

5. PERFORMING THE TESTS

The purpose of the experiments consists in:

-determining the conveyor's flow rates at various travelling speeds, using the relation (4)

-verifying the applicability of the relationship (4)

- proposing original solutions to increase the flow transported with the conveyor set at the upper limit of inclination (when the material begins to slide).

5.1 Determining the characteristics of the material used for experiments

All the experiments were performed using washed and dried construction sand.

a. Determining the angle of repose

The angle of repose was calculated experimentally using two methods of determination, as shown in Figure 4, with identical results. The angle of repose at rest, ρ, was determined in the following way:

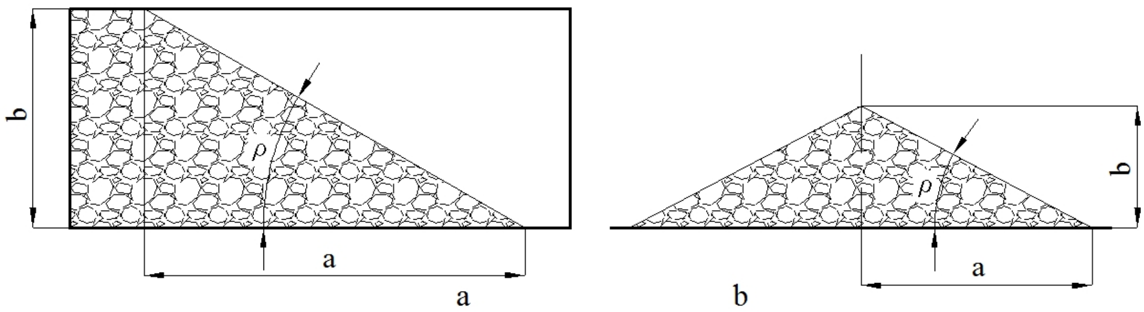

Fig. 4. Experimental determination of the angle of repose at rest a – method 1; b – method 2

In both approaches, the opposite leg b and the adjoining leg a of the angle of repose at rest ρ were measured accurately, as can be seen in Figure 4 a and b.

ρ value was determined using the equation:

$$\rho = arctg\frac{b}{a}$$

The results obtained from using Method 1 (Figure 4. a) were:

$$a = 162 \text{ mm}; \ b = 84 \text{ mm}; \ \frac{b}{a} = \frac{82}{162} = 0{,}5062$$

Therefore: $\rho = arctg\frac{b}{a} = arctg0{,}5062 = 26{,}84^0$

The results obtained from using Method 2 (Figure 4.b) were: $a = 135$ mm; $b = 68$ mm;

$$\frac{b}{a} = \frac{68}{135} = 0{,}5037$$

Therefore: $\rho = arctg\frac{b}{a} = arctg0{,}5037 = 26{,}73^0$

Both from Method 1 and from Method 2 there resulted, with an accuracy deemed acceptable, the values:

$$\rho_1 = 26{,}84^0 \ ; \qquad \rho_2 = 26{,}73^0$$

An average value for ρ was calculated and selected:

$$\rho = \frac{\rho_1 + \rho_2}{2} = \frac{26{,}84 + 26{,}73}{2} = 26{,}79^0$$

We select: $\rho = 26{,}8^0$

b. Determining the volumetric weight of the sand.

To determine the volumetric weight of the material we used a cylindrical vessel with the volume known to the third exact decimal place:

$V = 1{,}253 \ \mathrm{dm}^3 = 0{,}001253 \ \mathrm{m}^3$

The vessel was filled with material and weighed with an electronic scale; the resulted weight was G1 = 2,125kg. Next, the vessel was emptied and weighed with the same scale; the resulted weight was G2 = 0.200 kg.

The weight of the material in the vessel was calculated as follows:

$$G = G1 - G2 = 2{,}125\text{-}0{,}200 = 1{,}925 \ kg \ = 0{,}001925 \ t$$

and volumetric weight:

$$\gamma = \frac{G}{V} = \frac{0{,}001925}{0{,}001253} = 1{,}536 \ \mathrm{t/m^3}$$

c. Determining the sand grain size.

The grain size stated in the documentation provided by the producer was checked in the laboratory, using an oscillating riddle (Figure 5) provided with a set of four sieves of 0.75 mm, 1 mm, 1.5 mm and 2 mm mesh. The experiment placed the material in the category of grains between a´ = 0.5…10mm

The basic components of the oscillating riddle are shown in Figure 5.

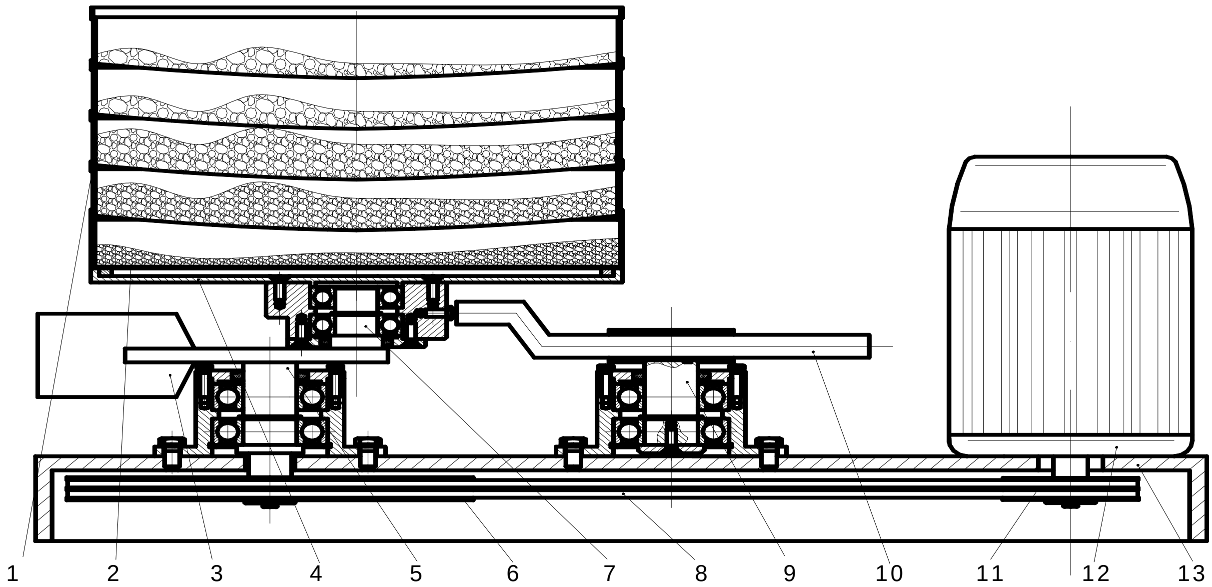

Fig. 5. Basic Components of the Oscillating Riddle

1- sieve; **2**- collector; **3**- counterweight; **4**- oscillating support; **5**- eccentric shaft; **6**- driven pulley; **7**- eccentric; **8**- trapezoidal belt; **9**- rock shaft; **10**- anti rotation lever; **11**- driving pulley; **12**- three-phase motor; **13**- frame

Table 2 shows the grain size distribution of the material weight, determined initially for a volume of 1.253 dm^3 weighing 1.925 kg (for which the experiments intended to determine the angle of repose at rest were performed) then calculated for a volume of $1\mathrm{m}^3$.

Table 2

Value $a´$ mm	$a´ \le 0{,}75$	$0{,}75 \le a´ \le 1$	$1 \le a´ \le 1{,}5$	$1{,}5 \le a´ \le 2$	$2 \le a´ \le 10$
Weight kg/1,253dm^3	0,125	0,320	1,250	0,180	0,05
weight kg/m^3	99,76	255,39	997,61	143,66	39,90

5.2 Determining the conveying system's flow rates at various travelling belt speeds for horizontal conveyors

The flow rate of the experimental system for various belt speeds of advance is calculated using the relation (4) in its final form [2] [3]:

$$Q = 5{,}846 \cdot v \quad \text{t/h}$$

The flow values resulting from the above-mentioned relation and the flow values determined experimentally are listed in Table 3, and the graphs of the function *Q=f(v),* for both the theoretical and the experimental methods, are shown in Figure 6.

In order to be able to use the experimental system, the relation for Q, as expressed in t/h, is transformed so that the Q is expressed in kg/min [4].

$$Q = 5{,}846 \cdot \frac{1000}{60} \cdot v = 97{,}43 \cdot v \quad \text{kg/min}$$

Table 3

v m/s	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
Q_t kg/min	0	9,74	19,48	29,23	38,97	48,72	58,46	68,20	77,94	87,69	97,43
Q_{exp} kg/min	0	8,70	17,20	25,80	34,30	42,50	-	-	-	-	-

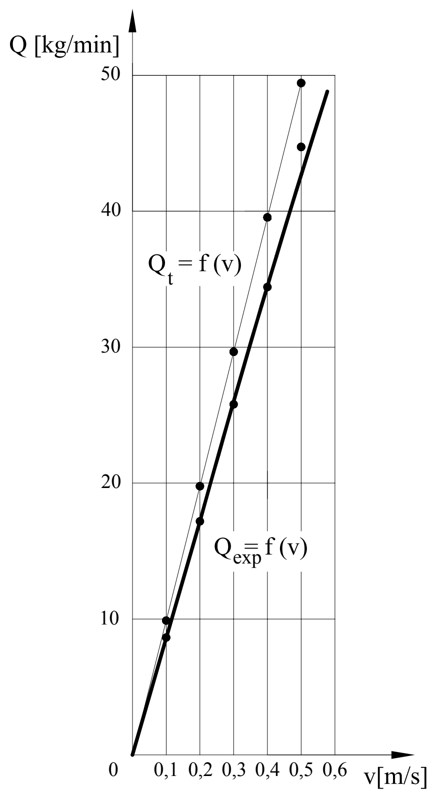

Fig. 6. Function graphs $Q_t = f(v)$ and $Q_{exp} = f(v)$

As can be noticed, looking at the theoretical flow values *Qt* and at the graph shown in Figure 6., the function *Qt=f(v)* is a straight line, which means that the theoretical flow rate increases proportionally to the increase in the speed of travel of the conveyor's belt.

This proportional dependence could not be obtained experimentally as well, since, when the material pours on the conveyor's belt, it tends, due to inertia, to fall behind the belt and pile up due to the new quantities of material coming from the dispenser.

For this reason, the material reaches the edge of the belt and overflows, therefore the flow Q_{exp} needs to be decreased from the feeder hopper's dispenser. This tendency gets stronger as the belt speed v and the flow Q_{exp} falling on the belt increase.

The experiments were performed using an experimental conveying system equipped with a flexible transmission body (belt) made of polyvinyl chloride-impregnated cloth.

This type of material, when coming into in contact with sand, creates a kinetic coefficient friction torque lower than the sand-rubber torque, which allows the process to be intensified and noticed.

5.3 Verifying the applicability of the relation (4) for the flow of a horizontal conveyor with a flexible transmission body

As can be seen, looking at the values shown in Table 4 and expressed graphically in Figure 6, for the relationship between the conveyor's flow rate and the travelling speed of the flexible transmission body, values which were obtained by applying the relation (4) for flow.

$$Q_t = 5{,}846 \cdot v \quad \text{t/h} \qquad (5)$$

or

$$Q_t = 5{,}846 \cdot \frac{1000}{60} \cdot v = 97{,}43 \cdot v \quad \text{kg/min} \qquad (6)$$

they do not match the values determined experimentally using the conveying system presented in section 5.

There can be noticed a significant difference between the theoretically and the experimentally calculated flow values, at the same travelling speeds. The difference is expressed as percentage in Table 4.

Table 4

v	0	0,1	0,2	0,3	0,4	0,5
Q_t	0	9,74	19,48	29,23	38,97	48,72
Q_{exp}	0	8,70	17,20	25,80	34,30	42,50
Q_t / Q_{exp}	-	1,119	1,132	1,133	1,136	1,146
%	-	11,9	13,2	13,3	13,6	14,6

As can be seen looking at Table 4, the flow values calculated based on the relation (4) are higher than those determined experimentally, by a percentage increasing as the speed of the flexible transmission body increases, and ranging between 11.9% and 14.6%,.

This finding leads us to propose, for determining the theoretical flow, only for smooth surface traction and transport bodies, a relationship of the form:

$$Q_t = 5{,}846 \cdot \frac{v}{\alpha_v} \quad \text{t/h} \qquad (7)$$

- where: α_v is an improper value coefficient of velocity, with estimated values in accordance with the values given in Table 4 for the studied material. The values of the A_v coefficient are specific to each material transported.

5. CONCLUSIONS

Following the experiments performed, we have come to the conclusion that the actual flow of a flexible, plane traction and transport body conveyor is not proportional to the speed of the transport body, in accordance with the relations (5) and (6), but it also depends on the α_v coefficient of velocity, whose value increases as the travelling speed of the transport body increases.
In accordance with Table 4 and the graph shown in Figure 6, resulting from the experiments performed, we are propsing a relation of the form (7), which reflects more accurately the flow variation according to the speed of the transport body.

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