Experimental expression of the resistance of belt conveyor's plough

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Abstract. The article deals with a theoretical expression of resistances that occur in pushing loose material off the conveyor belt surface with a single-sided plough. The working branch of a belt conveyor is designed in a flat, single-idler arrangement. Theoretical prerequisites and derivations are practically tested on a belt conveyor model in the laboratory of the Department of Research and Testing of the Institute of Transport at the Engineering Faculty of VSB-TU in Ostrava.

1 Introduction

Discharging of conveyed materials out of a belt conveyor may be performed using three basic methods: the conveyed material is most often discharged through the end drum of the belt conveyor (Fig. 1,a) [4]; if discharging the material at a certain point of the conveyor track is required that may have any distance along the length of the track, ploughs (single-sided and double-sided) are used (Fig. 1,b). For a continuous discharge of conveyed material along the entire length of the belt conveyor, tripper cars are used (Fig. 1,c).

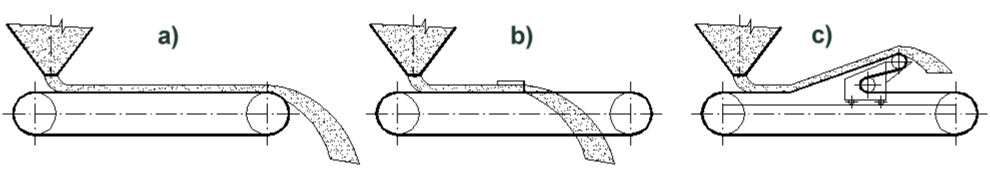

Fig. 1. Methods of discharging the conveyed material off the belt conveyor a) over the end drum, b) with a plough, c) with a tripper car.

2 Description of plough

The ploughs of conveyed materials are divided to single-sided and double-sided ploughs, see Fig. 2 [3]. The ploughs are located in a specific point of the belt conveyor track and if necessary they may be located in more points of the track or they can be

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designed as removable. They are moved to their working positions manually, or by pneumatic or hydraulic linear motors.

2.1 Single-sided plough

We assume that on a conveyor belt an isolated grain is conveyed with its weight m [kg], of a nonspherical shape (the grain cannot rotate around its centre) and speed v [$m.s^{-1}$], which is equal to the conveyor belt speed v_p [m/s].

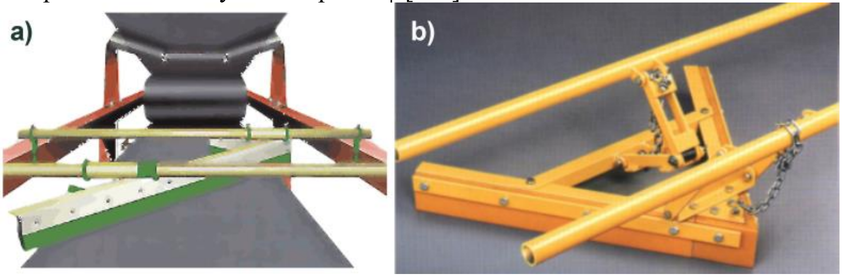

Fig. 2. Structural design of conveyed material plough a) single-sided, b) double-sided (V-shape).

The peripheral force F [N] on the driving drum of the belt conveyor is given by the sum of partial resistances that may be defined, according to [5-8], as: Main resistance F_H [N], resistance from material lifting F_{St} [N], secondary resistance F_N [N], and additional main F_{S1} [N] and secondary resistances F_{S2} [N].
At the time when the grain meets the single-sided plough, see Fig. 4,b, the peripheral force F [N] on the driving drum of belt conveyor increases by the value ΔF [N], see Fig. 5,a. The maximum increase value of peripheral force ΔF [N] on the driving drum of the belt conveyor occurs if the single-sided plough is located perpendicularly to the conveyor belt's longitudinal axis (β = 90 [deg], see Fig. 3,a). The increase value amount of the momentary pulling force is expressed as, see Fig. 5:

$$\Delta F = G.\ \mu_p = m.\ g.\ \mu_p \ [N] \quad (1)$$

μ_p - friction coefficient between conveyed material and conveyor belt surface [-].

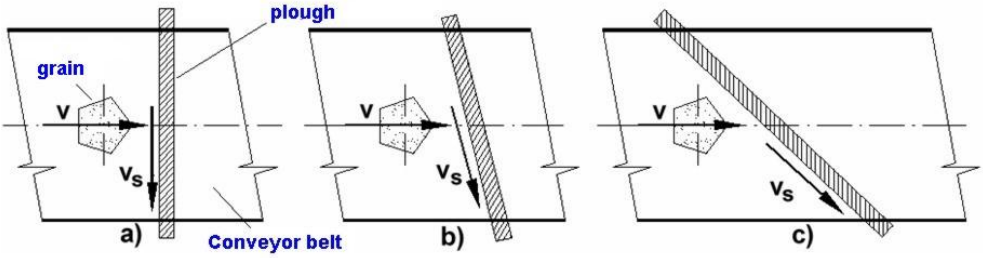

Fig. 3. Dependence of the momentary movement speed of grain v_s [$m.s^{-1}$] in the direction of plough depending on the tilt angle of plough β [deg].

In practice, the plough of loose materials is not designed in perpendicular direction to the conveyor belt's longitudinal axis (impossibility of pushing the material off the conveyor belt surface). The increase in peripheral force ΔF [N] on the driving drum depending on the tilt angle of the single-sided plough is shown in Fig. 7 (the graph values are given for the following parameters: isolated grain weight m = 10 kg, μ_p = 0,3, β = 0 ÷ 90 deg). It is logical that the peripheral force increase on the driving drum of belt conveyor is direct proportional to the increasing length of a filled conveyor to infinity. In practice, the plough of loose materials is located at angle β < 90 deg to the conveyor belt's longitudinal axis, see for example Fig. 3,b and Fig. 3,c.

At the time of contact of the conveyed grain with the plough at angle β [deg] to the conveyor belt's longitudinal axis the carried grain starts to move along the plough at speed v_t [m/s]. Depending on the tilt angle of the plough β [deg] the momentary speed v_t [m/s] has a different value, see Fig. 3.

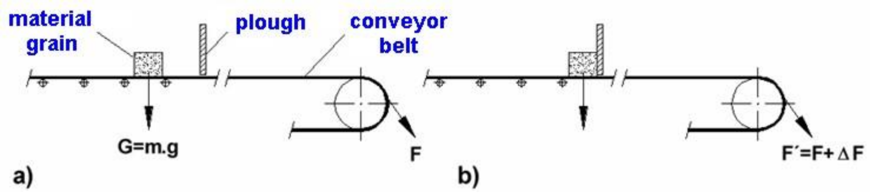

Fig. 4. Conveyance of an isolated grain of non-spherical shape by belt conveyor.

At the time of contact of the conveyed grain with the plough at angle β [deg] to the conveyor belt's longitudinal axis the carried grain starts to move along the plough at speed v_t [m/s]. Depending on the tilt angle of the plough β [deg] the momentary speed v_t [m/s] has a different value, see Fig. 3.

The momentary speed values v_{ts} [m/s] of the grain movement in the direction of the plough are expressed according to Fig. 6 and relation (3).

$$v_t = v.\cos\beta \text{ [m/s]} \tag{2}$$

$$v_{ts} = v_t . c \text{ [m/s]} \tag{3}$$

where, c - the constant following the movement direction $c = 0{,}8 \div 0{,}85$.

3 Theoretical expression of the movement of an isolated grain along the plough

From Fig. 6, individual components of resistances against the movement of an isolated grain along the plough of a belt conveyor may be determined.

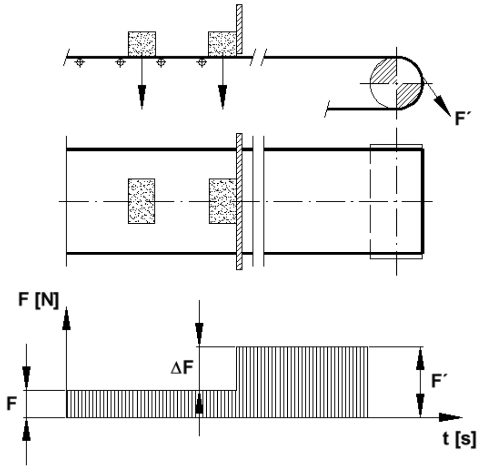

Fig. 5. The course of peripheral force on the belt conveyor's driving drum.

The friction force derived by the friction of conveyed material against the conveyor belt surface:

$$F_1 = m.\, g.\, f_p \ [N] \tag{4}$$

where f_p [-] - the friction coefficient of conveyed material against the conveyor belt surface.
Friction force produced by the conveyed grain of material towards the plough:

$$F_2 = K.\, \sin\beta.\, f_s \ [N] \tag{5}$$

where f_s [-] - friction coefficient between the moving grain and the plough,
K [N] - force delivered by the belt conveyor drive.
Based on Fig. 6, the equation of motion may be set up:

$$m.\, \frac{d^2x}{dt^2} + F_1 + F_2 = K.\, \cos\beta \ [N] \tag{6}$$

After putting down the expressions from relations (4) and (5), we obtain:

$$m.\, \frac{d^2x}{dt^2} + m.\, g.\, f_p + K.\, \sin\beta.\, f_s = K.\, \cos\beta \ [N] \tag{7}$$

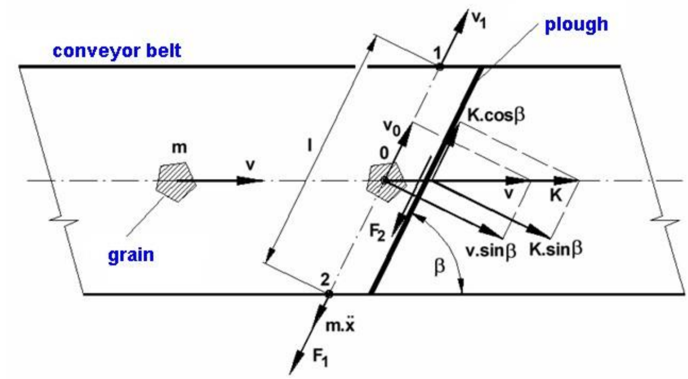

Fig. 6. Resolution of acting forces at pushing an isolated grain by the plough off the conveyor belt surface.

By adjusting the relation (7), we obtain:

$$\frac{d^2x}{dt^2} = \frac{K}{m}.\, [\cos\beta - f_s.\, \sin\beta] - g.\, f_p = C \ [N] \tag{8}$$

$$\frac{dx}{dt} = v = A.\, t + A_1 \tag{9}$$

$$x = \frac{A.\, t^2}{2} + A_1.\, t + A_2 \tag{10}$$

From the edge Lagrange's conditions the following results:
for $t = 0 \Rightarrow v = v_0 \Rightarrow A_1 = v_0$ and $t = 0 \Rightarrow x = 0 \Rightarrow A_2 = 0$
where v_0 [m/s] - the initial speed of moving grain in point 0, we assume:

$$v_0 = v.\, \cos\beta.\, c \ [m/s] \tag{11}$$

where c [-] - the constant following the direction change $c = 0{,}8 \div 0{,}85$.

$$x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4.\, a.\, c}}{2.\, a} \Rightarrow \text{for } a = 1\text{: } x_{1,2} = -\frac{b}{2} \pm \sqrt{\left(\frac{b}{2}\right)^2 - c} \tag{12}$$

The gravity centre of the grain will run path l [m] for time t_1 [s]

$$l = \frac{A.\, t_1^2}{2} + v_0.\, t_1 \ [m] \Rightarrow t_1^2 + \frac{2.\, v_0}{A}.\, t_1 - \frac{2.\, l}{A} = 0 \Rightarrow$$

$$\Rightarrow\ t_1 = -\frac{v_0}{A} + \sqrt{\frac{v_0^2}{A^2} + \frac{2.\,l}{H}} \ \Rightarrow\ t_1 = \frac{\sqrt{v_0^2 + 2.\,A.\,l} - v_0}{A}\ [s] \tag{13}$$

$$v_1 = A.\,t_1 + v_0\ [m/s] \tag{14}$$

assumption in time t = 0 [s]: $v_1 = v_0$

$$t_1 = \frac{v - v_0}{A}\ [s] \tag{15}$$

$$v = \sqrt{v_0^2 + 2.\,A.\,l} \ \Rightarrow\ A = \frac{v^2 - v_0^2}{2.\,l} \tag{16}$$

$$t_1 = \frac{v - v_0}{A} = \frac{(v - v_0).\,2.\,l}{v^2 - v_0^2} = \frac{2.\,l}{v + v_0}\ [s] \tag{17}$$

$$m = \frac{Q}{3{,}6}.\,t_1 = \frac{Q}{3{,}6}.\,\frac{2.\,l}{(v + v_0)}\ [kg] \tag{18}$$

$$C = \frac{v^2 - v_0^2}{2.\,l} \tag{19}$$

$$A = \frac{K}{m}.\,[\cos\beta - f_s.\,\sin\beta] - g.\,f_p \ \Rightarrow\ K = \frac{(C + g.\,f_p).\,m}{\cos\beta - f_s.\,\sin\beta} = \frac{v^2 - v_0^2 + 2.\,l.\,g.\,f_l}{(\cos\beta - f_s.\,\sin\beta).\,(v + v_0)}.\,\frac{Q}{3{,}6} \tag{20}$$

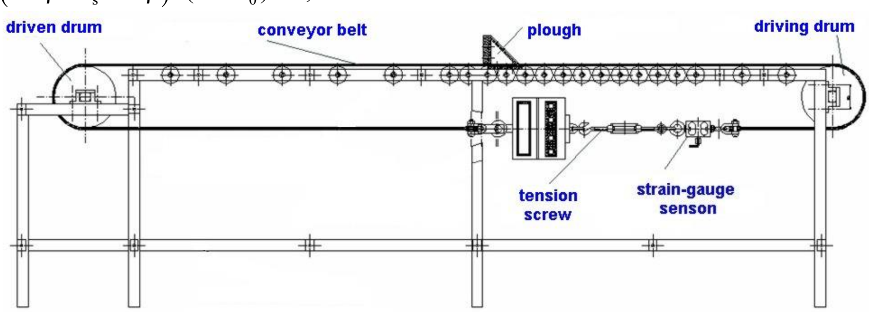

Fig. 7. Belt conveyor model fitted with a single-sided plough.

3.1 Description of the belt conveyor plough model

In the laboratory of the Department of Research and Testing of the Institute of Transport, a structural design and realization of a model of a single-sided plough of belt conveyor was made, see Fig. 7 according to the drawings necessary for the delivery of individual components of contacted companies.

Acc. to [2], an EP 250/2 conveyor belt is chosen, width B = 500 mm, thickness of the upper cover layer s_1 = 2 mm, thickness of the lower cover layer s_2 = 1 mm, overall thickness of conveyor belt s = 5 mm, thickness of frame $s_3 = s - s_1 - s_2 = 5 - 2 - 1 = 2$ mm.

The rubber conveyor belt of the design TAURUS 500 EP 250/2N 202045 4 3 13VH Wroclaw was supplied by Stomil Wolbrom s.a. based on defined dimensional and strength properties.

Acc. to [1, page 3, Table 2] the permitted tensile strength of conveyor belt is f_0 = 250 N/mm; the permitted tension load is f_t = 25.0 N/mm.

Permitted tension load:

$$f_t = 25{,}0.\ B = 25{,}0.\ 500 = 12\ 500\ [N] = 12{,}5\ kN \quad (21)$$

The maximum force F_{max} [N] in a conveyor belt produced by tensioning of the model conveyor belt:

$$F_{max} = m_v.\ g = 1000.\ 9{,}81 = 9\ 810\ N \quad (22)$$

where m_v [kg] - the weight taken from electronic scales (the weight is produced by the tensioning screw and the tensioning device of the reversing drum).

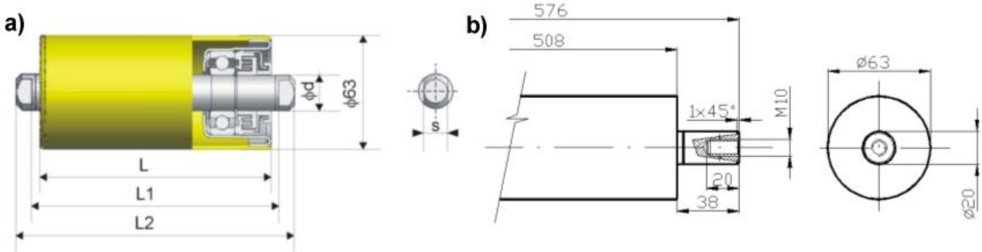

Fig. 8. Carrying idler of belt conveyor's belt.

Use of the permitted tension load:

$$x\ [\%] = \frac{100.\ F_{max}}{f_t} = \frac{100.\ 9810}{12500} = 78{,}48\ \% \quad (23)$$

Acc. to [1, page 16, Table 12] the smallest diameter of driving drum d = 200 mm is chosen (for the insert material it is polyester and a combination of E, EP, Evs, EvsPvs; for the thickness of frame s_3 = 2 mm and for the use of permitted tension load f_t = from 60% to 100%).
Acc. to [1, page 16, Table 12] the smallest diameter of reversing drum d = 160 mm is selected (for the insert material it is polyester and combination of E, EP, Evs, EvsPvs; for thickness of frame s_3 = 2 mm and for the use of permitted tension load f_t = from 60% to 100%).
The reversing drum and the driving electric drum, type EB 220 - 510 x 0,4 –1,5 were purchased from Privat STS Pacov. The drums 220 mm in diameter are made of steel, they rotate in bearings pressed on shafts 40 mm in diameter.

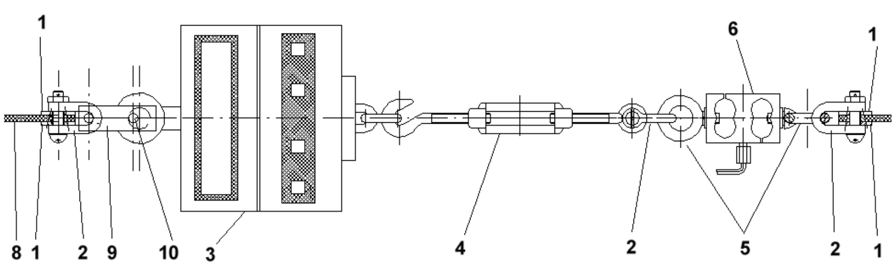

Fig. 9. Design of tensioning, structural and measuring members on the conveyor belt in the reversing branch of the belt conveyor model.

Based on drawings the carrying idlers of the conveyor belt (Fig. 8,a) were made by Tranza a.s. based in Břeclav; the dimensions comply with CSN 261102 in accordance with ISO 1537. The idlers of the manufacturer's type designation "smooth idler 63 x 500/6204, 3-20024-00030" are in diameter D = 63 mm, length L = 508 mm, length L_2 = 576 mm. The idler jacket is made of a steel tube with the wall thickness of 2.5 mm, the idler is fitted with a two-level labyrinth seal with grease pre-chamber. The ends of idler axes were adjusted based on drawings to the shape acc. to Fig. 8,b.

The tensometric sensor 6 (Fig. 9), type designation RSCAC3/1t with a range from 0 to 1000 kg, measures the axial tension load; it is a tensometric sensor of tensile load, accuracy class C3 acc. to OIML R60 with cable 5 mm in diameter. The sensor was purchased from HBM (Hottinger Baltwin Messtechnik).
Data on the derived required pretension of the conveyor belt and for the calibration of the sensor were obtained using electronic measuring scales 3 (Fig. 9), CS series, (specification of type CS-1T, capacity 1000 kg, division mark 0.5 kg, manufacturer UWE Crane Scale, supplier for the Czech Republic RVS (Regulation - Scales - Systems) spol. S r.o., Tovární 223, 357 35 Chodov).
The conveyor belt (8), see Fig. 9, final length L = 5200 mm, is by means of the yoke (2) (specification acc. to DIN 82101). The necessary tensile strength and pretension in the conveyor belt is produced by the tensioner (4) of hook-eye design, specification acc. to DIN 1480. The tensometric sensor of tensile load (6), type designation RSCAC3/1t, is fitted on both its ends with suspension eyes (5) with thread M12, specification acc. to DIN 580.
The conveyor's load-carrying structure, the grasping device of shafts, drums and tensioning devices, see Fig. 10, were self-made in the laboratory of the Department of Research and Testing of the Institute of Transport. The plough itself is comprised of an aluminium alloy plate 1450 x 100 x 16 mm in size.

3.2 Measuring procedure

1. Measuring the resistance against the movement K_0 [N] of conveyor belt, without the presence of conveyed loose material;
2. Measuring the resistance against the movement K [N] of conveyor belt filled with loose material;
3. Measuring the resistance against the movement K_s [N] of conveyor belt filled with loose material at discharging the material with the plough (as the function of the plough's tilt angle against the conveyor belt's longitudinal axis β [deg]).

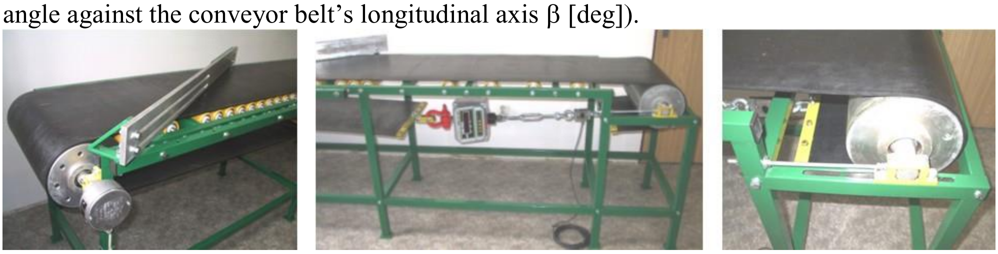

Fig. 10. Belt conveyor model fitted with a single-sided plough.

4 Conclusion

On the belt conveyor model (Fig. 10), which is equipped with a single-sided plough, resistance was determined that occurs at pushing the loose material off the conveyor belt surface with a single-sided plough. These resistances were expressed for different tilt angles of plough β [deg], a different speed of the belt conveyor movement v [$m.s^{-1}$] and for different conveyed materials. First, resistance against the movement K_0 [N] of the conveyor belt was expressed, without the presence of conveyed loose material, then resistance against the movement K [N] of the conveyor belt filled with loose material, and finally resistance against the movement K_s [N] of the conveyor belt filled with loose material at discharging the material using the plough (as the function of the plough's tilt angle against the conveyor belt's longitudinal axis β [deg]).

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