COMPARISON OF THE METHODOLOGIES FOR DETERMINING THE CROSS SECTION OF THE MATERIAL ON A MOVING CONVEYOR BELT

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ABSTRACT. Three methodologies for determining the cross section of the transported material are discussed: the first one - based on the DIN German standard for the calculation of belt conveyors used by the Dunlop company; the second one - based on the ISO and CEMA American standards for calculation used by the Sandvik company; and the third one - based on the GOST Russian standard. The second methodology assumes that the form of the material is a segment of a circle, whereas the first and the third methodologies consider the form as an isosceles triangle. Calculations are accomplished with the three methodologies for a concrete solved example - a belt conveyor with three roll idlers with assigned length of the rollers, angle of inclination of the side rollers, and type of the transported material. In the calculations, the recommended values of the material surcharge angle are taken for the corresponding methodology.
The following conclusions are drawn: 1. When the recommended values of the material surcharge angle are used for the area of the material cross section, approximately equal values are received by the three methodologies; 2. In order to obtain an equal cross section area of the transported material, the value of the surcharge angle in the first and the third methodologies must be taken smaller than that in the second methodology.

Keywords: cross section of the material, surcharge angle, methodology

СРАВНЯВАНЕ НА МЕТОДИКИТЕ ЗА ОПРЕДЕЛЯНЕ НА СЕЧЕНИЕТО НА МАТЕРИАЛА ВЪРХУ ДВИЖЕЩА СЕ ТРАНСПОРТНА ЛЕНТА

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РЕЗЮМЕ. Разгледани са три методики за определяне на сечението на транспортирания материал: първата - по немския стандарт за изчисляване на лентови транспортьори DIN, използвана от фирма Dunlop; втората - по американските стандарти за изчисляване ISO и CEMA, използвана от фирма Sandvik; и третата - по руския стандарт за изчисляване ГОСТ. При втората методика се приема, че формата на материала е сегмент от окръжност, а при първата и третата методика – формата е равнобедрен триъгълник. Направени са изчисления по трите методики за конкретно решаван пример - транспортьор с триролкови опори със зададени дължина на ролките, ъгъл на наклон на страничните ролки и вид на транспортирания материал. При изчисленията са взети препоръчителните за съответните методики стойности на ъгъла на откоса на материала при движение.
Направени са следните изводи: 1. При използване на препоръчителните стойности на ъгъла на откоса на материала при движение за площта на сечението се получават приблизително еднакви стойности по трите методики; 2. За да се получи еднаква площ на сечението на транспортирания материал, трябва ъгълът на откоса на материала при движение по първата и третата методика да се приема по-малък от този по втората методика.

Ключови думи: сечение на материала, ъгъл на откос при движение, методика

Introduction

On a moving conveyor belt, the cross section of the transported material can be divided into two parts: lower part with the form of an isosceles trapezium with an area S_2, and upper part with the form of a segment from a circle with an area S_1 (Fig.2). The angle θ, between the tangent to the circle in the point of intersection of the circle with the belt, and the horizontal line, is called *surcharge angle*. This angle is used for determining the area of the cross section of the material in the methodology of the American standards ISO and CEMA, which is used by the Swedish company Sandvik (HA 200 Idlers design manual, Sandvik, 2008).

The surcharge angle (dynamic angle) θ is usually with 5° to 15° smaller than the angle of repose (static angle) θ_0, but in some materials it can be by 20° smaller. It is recommended that the surcharge angle θ be chosen from Table 1.

Table 1.
Surcharge angle of the material

Angle of repose of the material θ_o [º]				
0 - 19	20 - 29	30 - 34	35 - 39	40 - 50
Flow ability of the material				
Very high	High	Medium	Low	
Surcharge angle of the material θ [º]				
5	10	20	25	30

In the methodology of the German DIN 22101 standard (Phoenix conveyor belt design fundamentals, 2004), used by the Netherlands company Dunlop (Conveyor belt design and calculation, Dunlop, 2009), an *equivalent angle of surcharge β* (Fig.1) is introduced for determining the area of the cross section of the transported material. It is assumed that the area of the upper part of the cross section A_1 is equal to the area of an isosceles triangle with base angle β. The equivalent angle of surcharge β is smaller than the angle of surcharge θ, used in the first methodology.

The values of the angle β for the various materials are given in tables. At medium flow ability of the material (these are the majority of the materials), the angle β is recommended to be assumed as 15°, at low flow ability - to be β=20°, and at high flow ability - to be β=5° or 10°.

In the methodology of the Russian GOST standard (Vasiliev, 1991), it is assumed that the area of the upper part of the material's cross section A_1 (Fig.3) is equal to the area of an isosceles triangle with base angle φ (this is the angle of surcharge of the material). The area of the lower part of the cross section A_2 which is an isosceles trapezium is equal to the area of an isosceles triangle with base angle α'. For determining the area of the whole cross section, empirical coefficients are introduced.

The aim of the present study is the calculation of the area of the cross section using the three methodologies and the comparison of the results. A concrete example is solved - a belt conveyor with three roll idlers with a given length of the rollers, an angle of inclination of the side rollers, and the type of the transported material. In the calculations, the recommended values of the angle of surcharge for the corresponding methodology are taken.

Another aim of the study is to determine the ratio of the angles of surcharge of the material which must be accepted in the calculations in the different methodologies.

Determining the area of the cross section of the transported material in the different methodologies

Determining the area of the cross section in the methodology of the DIN 22101 standard

The area of the cross section of the material A is a sum of the areas of the cross sections A_1 and A_2 (Conveyor belt design and calculation, Dunlop, 2009) (Fig.1):

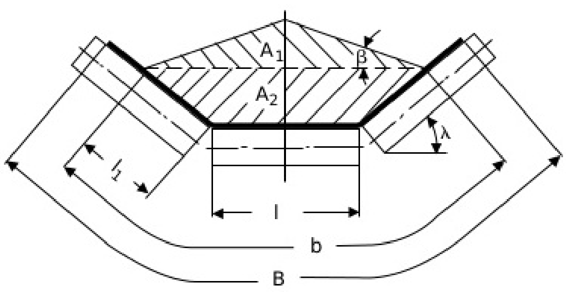

Fig.1. Scheme for determining the area of the cross section of the transported material according to DIN 22101

$$A = A_1 + A_2 \quad (1)$$

The area of the section A_1 which is an isosceles triangle is equal to:

$$A_1 = \frac{x.h_1}{2} = \frac{x}{2}.\frac{x}{2}.tg\beta = 0,25.tg\beta.x^2, \quad (2)$$

where β is an equivalent angle of surcharge of the material.

The length of the base of the triangle x is equal to:

$$x = l + 2.\left(\frac{b-l}{2}.\cos\lambda\right) = l + (b-l).\cos\lambda, \text{ m}, \quad (3)$$

where:
l is the length if the rollers;
b is the working width of the belt;
λ is the angle of inclination of the side rollers.

When substituting equation (3) in equation (2), it is received:

$$A_1 = 0,25.tg\beta.\left[l + (b-l).\cos\lambda\right]^2 \quad (4)$$

The area of the section A_2 which is an isosceles trapezium is equal to:

$$A_2 = \frac{x+l}{2}.h_2 = \frac{x+l}{2}.l_1.\sin\lambda \quad (5)$$

After substitution of equation (3) in equation (5), it is received:

$$A_2 = \frac{l + 2.\left(\frac{b-l}{2}.\cos\lambda\right) + l}{2}.l_1.\sin\lambda =$$

$$= \frac{l + 2.(l_1.\cos\lambda) + l}{2}.l_1.\sin\lambda = l_1.\sin\lambda\left(l + l_1.\cos\lambda\right), \quad (6)$$

where l_1 is the working length of the side rollers and is determined by equation (7):

$$l_1 = \frac{b-l}{2} \quad (7)$$

For the working length of the belt, it is assumed:

$$b = 0,9.B - 0,05 \text{ , m ,} \quad (8)$$

where B [m] is the width of the belt.

The length of the rollers for three roll idlers is assumed from Table 2.

Table 2.
Recommended length of the rollers l [mm]

Width of the belt B [mm]	500	650	800	1000
Three roll idlers l [mm]	200	250	315	380

1200	1400	1600	1800	2000	2200	2400
465	530	600	670	750	800	900

When β=15° (the recommended value when a composite of sand and gravel is transported), λ=30°, and B=1.2m, it is received: l=0.465m (from Table 2); b=1.03m (from equation (8)); A_1=0.061m^2 (from equation (4)); l_1=0.2825m (from equation (7)); A_2=0.1m^2 (from equation (6)); and A=0.161m^2 (from equation (1)).

In Table 3 (Conveyor belt design and calculation, Dunlop, 2009), the volume capacities of the conveyors Q_v [m^3/h] are given at belt velocity v=1m/s, according to the methodology of the DIN 22101 standard used by the company Dunlop.

Table 3.
Volume capacities of the conveyor Q_V [m³/h] for three roll idlers at belt velocity v=1m/s according to DIN 22101

B [mm]	β [°]	Q_V [m³/h] at λ [°] 20	**30**	35	40	45
	0	21	30	34	-	-
400	10	35	43	47	-	-
	15	42	50	53	-	-
	20	50	57	60	-	-
	0	36	51	58	-	-
500	10	59	73	79	-	-
	15	72	84	90	-	-
	20	85	97	102	-	-
	0	67	95	108	118	127
650	10	109	134	145	153	159
	15	131	155	165	176	176
	20	155	176	184	190	193
	0	105	149	168	185	198
800	10	171	210	227	240	249
	15	206	243	257	268	276
	20	243	276	289	299	303
	0	173	246	278	304	326
1000	10	280	344	370	391	407
	15	336	396	419	436	448
	20	394	449	469	484	492
	0	253	360	406	445	477
1200	10	411	505	543	573	596
	15	493	**580**	614	640	658
	20	578	659	688	709	722
	0	355	504	567	622	666
1400	10	572	703	755	797	828
	15	685	806	852	888	912
	20	803	915	954	964	1001
	0	472	669	753	825	883
1600	10	758	931	1000	1055	1096
	15	906	1067	1128	1175	1207
	20	1062	1209	1263	1301	1323
	0	605	858	965	1057	1131
1800	10	969	1194	1279	1350	1402
	15	1159	1364	1443	1502	1543
	20	1357	1546	1614	1662	1690
	0	750	1064	1197	1311	1404
2000	10	1204	1478	1588	1675	1741
	15	1439	1694	1791	1865	1916
	20	1685	1919	2003	2064	2099
	0	948	1343	1509	1650	1765
2200	10	1509	1855	1990	2099	2178
	15	1801	2121	2241	2332	2393
	20	2107	2399	2503	2576	2618

B - width of the belt,
β [°] - angle of surcharge of the material,
Q_v [m³/h] - volume capacity,
λ [°] - angle of inclination of the side rollers.

The area of the cross section of the transported material is received by the formula:

$$A = \frac{Q_V}{3600}, \text{m}^2 \tag{9}$$

For the concrete example, when *β*=15°, *λ*=30° and *B*=1.2m, from Table 3 it is checked that Q_v=580m³/h and for the area of the cross section from formula (9), it is received *A*=0.161m². Consequently, for the areas of the cross section determined by formula (1) and Table 3, equal values are received.

Determining the area of the cross section in the methodology of the ISO (CEMA) standard

The area of the cross section of the material *S* is a sum of the areas of the cross sections S_1 и S_2 (Hrabovsky, 2011) (Fig.2):

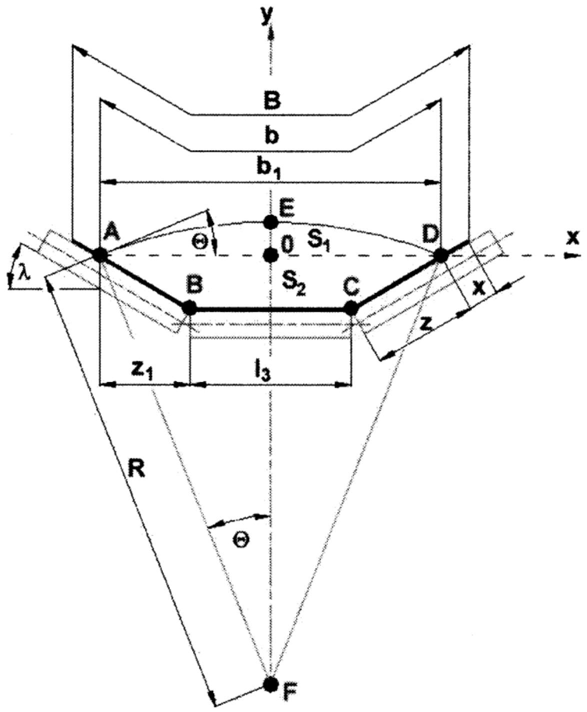

Fig. 2. Scheme for determining the area of the cross section of the transported material according to ISO (CEMA)

$$S = S_1 + S_2 \tag{10}$$

The area of the section S_1 which is the segment *AED* is the substitution of the area of the sector *FAEDF* and the areas of the triangles *FA0* and *FD0*.

$$S_1 = S_{AED} = S_{FAEDF} - S_{FAO} - S_{FDO} \tag{11}$$

The area of the sector *FAEDF* is:

$$S_{FAEDF} = \pi.R^2.\frac{2.\theta}{2.\pi} = R^2.\theta, \tag{12}$$

where:
R is the radius of the arc *AED*;
θ [rad] is half of the central angle of the arc *AED*.

After the substitution of the angle *θ* in [°], formula (12) is transformed to:

$$S_{FAEDF} = \frac{\pi.\theta}{180}.R^2 \quad (13)$$

The areas of the triangles *FA*0 и *FD0* are equal to:

$$S_{FAO} = S_{FDO} = \frac{1}{2}.R.\sin\theta.R.\cos\theta = \frac{1}{2}.R^2.\sin\theta.\cos\theta \quad (14)$$

After substituting equations (13) and (14) in equation (11), it is received:

$$S_1 = \frac{\pi.\theta}{180}.R^2 - 2.\frac{1}{2}.R^2.\sin\theta.\cos\theta = \\ = \frac{1}{2}.R^2.\left(\frac{2.\pi.\theta}{180} - \sin 2\theta\right) \quad (15)$$

The radius of the arc *AED* is equal to:

$$R = \frac{z.\cos\lambda + \frac{l_3}{2}}{\sin\theta} = \frac{2.z.\cos\lambda + l_3}{2.\sin\theta}, \quad (16)$$

where:
z is the working width of the side rollers;
l_3 is the length of the rollers.

After the substitution of equation (16) in equation (15), the area of the cross section S_1 is finally obtained:

$$S_1 = \frac{1}{2}.\left(\frac{2.z.\cos\lambda + l_3}{2.\sin\theta}\right).\left(\frac{2.\pi.\theta}{180} - \sin 2\theta\right), \quad (17)$$

where:

$$z = \frac{b - l_3}{2} \quad (18)$$

The working width of the belt *b* is determined by formula (8).

The area of the section S_2 is determined by a formula analogous to formula (6):

$$S_2 = z.\sin\lambda.\left(l_3 + z.\cos\lambda\right) \quad (19)$$

When θ=25° (the recommended value when a composite of sand and gravel is transported, or it is accepted from Table 1 at θ_0=38°), λ=30°, and *B*=1.2m, it is received: l_3=0.465m (from Table.2); *b*=1.03m (from formula (8)); *z*=0.2825m (from formula (18)); S_1=0.069m^2 (from formula (17)); S_2=0.1m^2 (from formula (19)); *S*=0.169m^2 (from formula (10)).

In Table 4 (HA 200 Idlers design manual, Sandvik, 2008), the areas of the cross section of the transported material are given according to the methodology of the ISO (CEMA) standard, used by the company Sandvik. For the concrete example, when θ=15°, λ=30°, and *B*=1.2m, it is checked that *S*=0.169m^2. Consequently, equal values are received for the areas of the cross section determined by formula (10) and Table 4.

In order to receive equal areas of the cross section in the two examined methodologies (DIN and ISO), it must be assumed that β=16.5° and then *A*=*S*=0.169m^2. Consequently, the ratio β/θ=16.5°/25°=0.67.

Determining the area of the cross section in the methodology of the GOST standard

The area of the cross section of the material *F* is a sum of the areas of the sections A_1 and A_2 (Vasiliev, 1991) (Fig.3):

$$A = A_1 + A_2 \quad (20)$$

Table 4.
Area of the cross section of the transported material for three roll idlers S [m^2] according to ISO (CEMA)

λ [°]	B [mm]	θ [°] 10	15	20	**25**	30
20	500	0.015	0.017	0.020	0.022	0.026
	650	0.027	0.031	0.035	0.039	0.047
	800	0.042	0.049	0.055	0.062	0.078
	1000	0.068	0.078	0.088	0.099	0.133
	1200	0.100	0.115	0.130	0.145	0.206
30	650	0.035	0.038	0.042	0.046	0.052
	800	0.054	0.060	0.066	0.072	0.081
	1000	0.087	0.096	0.105	0.115	0.144
	1200	0.128	0.141	0.155	0.169	0.208
	1400	0.176	0.94	0.213	0.232	0.289
	1600	0.232	0.256	0.281	0.306	0.383
	1800	0.296	0.327	0.358	0.390	0.489
	2000	0.368	0.406	0.445	0.485	0.544
35	800	0.059	0.064	0.070	0.075	0.083
	1000	0.095	0.103	0.112	0.121	0.135
	1200	0.139	0.151	0.164	0.177	0.197
	1400	0.191	0.209	0.226	0.245	0.272
	1600	0.252	0.275	0.298	0.322	0.358
	1800	0.322	0.351	0.380	0.411	0.456
	2000	0.400	0.436	0.472	0.510	0.566
45	800	0.066	0.071	0.075	0.080	0.088
	1000	0.106	0.113	0.121	0.129	0.142
	1200	0.155	0.166	0.177	0.189	0.207
	1400	0.214	0.229	0.244	0.260	0.285
	1600	0.282	0.302	0.322	0.343	0.376
	1800	0.360	0.385	0.410	0.437	0.479
	2000	0.447	0.478	0.510	0.542	0.594
	2250	0.543	0.581	0.620	0.659	0.670
	2500	0.705	0.754	0.804	0.856	0.883
	3000	1.023	1.094	1.166	1.240	1.262

B - width of the belt,
θ [°] - angle of surcharge of the material,
λ [°] - angle of inclination of the side rollers.

The area of the section A_1 which is isosceles triangle is equal to:

$$A_1 = \frac{b^2}{4}.tg\varphi = b^2.\frac{tg\varphi}{4}, \quad (21)$$

where:

b is determined by formula (8),
φ is the angle of surcharge of the material.

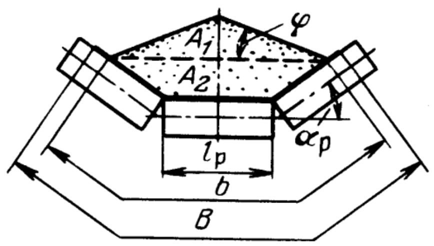

Fig. 3. Scheme for determining the area of the cross section of the material according to GOST

The area of the section A_2 which is isosceles trapezium is assumed to be equal to the area of an isosceles triangle with base *b* and base angle *α′*. Then it is received:

$$A_2 = \frac{b^2}{4}.tg\alpha' = b^2.\frac{tg\alpha'}{4}, \quad (22)$$

When equations (21) and (22) are substituted in equation (20), it is received:

$$A = b^2.\left(\frac{tg\varphi}{4} + \frac{tg\alpha'}{4}\right) = b^2.C, \quad (23)$$

The following values for the coefficient *C* are recommended for α_p=30° (Vasiliev, 1991): *C*=0.153 at *φ* =15° and *C*=0.174 at *φ* =20°. When *φ* =15°, α_p=30°, and *B*=1.2m it is received: *b*=1.03m (from formula (8)), *C*=0.153, and *A*=0.162m^2 (from formula (23)).

Conclusions

From the calculations using the three methodologies, the following conclusions are drawn:

1. For the area of the cross section of the transported material, close values are received for the concrete example solved: *A*=0.161m^2 using the DIN 22101 methodology, *S*=0.167m^2 using the ISO (CEMA) methodology, and *A*=0.162m^2 using the GOST methodology.

2. If the methodologies of DIN and GOST are used, a smaller value for the angle of surcharge of the material must be accepted, in comparison with the methodology of ISO (CEMA). For the concrete example solved, for the ratio of the angles of surcharge it is received 0.67, i.e. *β*≈0,67.*θ*. This is why, when a certain methodology is used, the surcharge angle for the given material must be taken according the recommendations and tables of this methodology.

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