Theoretical basis and industrial applications of energy – saving and increased durability belt conveyors

Jerzy Antoniak[1]

Teoretické základy a priemyselné aplikácie energeticky úsporných pásových dopravníkov so zvýšenou trvanlivosťou
Theoretical basis used to build new generation of belt conveyors is presented is this paper. These conveyors are characterized by better energy-saving parameters of the transport of run-of-mine and higher reliability. Examples of current technical solutions applied in coal mines have been used to present the results of this research. The paper is summarized with conclusions and remarks.

Key words: *energy-saving belt conveyors, theoretical basis, industrial application.*

Mining belt conveyors

The belt conveyors, due to their numerous advantages, in particular due to their construction of high strength and application of slow burning antistatic belts have become common means of transportation of the run-of-mine in underground hard coal mines and in mining plants of other minerals. It is assessed that in the national open cast mines of brown coal – about 270 kilometers, in the underground copper mines – 130 kilometers and in the hard coal mines – 605 kilometers of belt conveyors are installed.

A decrease in the total length of belt conveyors results from a widely understood restructuring process of the hard coal mines as well as from a progressive production concentration from a longwall face. Induction motors with a squirrel-cage rotor, for the voltage of 500 or 1000 Volts of the total power in the range of several hundred megawatts are used for driving these conveyors. In the underground mining industry the conveyors with the belt of 1.2-metre width, sporadically 1.0-metre width and more and more frequently the conveyors of the belt width 1.4 or 1.6 metres are used. Up till the present time the longest conveyors have been installed in the Bogdanka Colliery – 2.45 kilometres and in the Piast Colliery – 2.156 kilometres; at present the conveyor of 2.512-kilometre length has been installed in the Myslowice Colliery. A big group of installations includes the conveyors of the length from 1.0 to 2.0 kilometres. The curvilinear conveyors and conveyors with a spatial bend are used more and more frequently (Antoniak 2001).

The efficiency of the run-of-mine transportation by belt conveyors is high in comparison with other means of transportation. However, the costs of electric energy, in the range of 35 to 45 percent of the operational costs of conveyors affect the costs of the final product. In this connection intensive research and technical work, aimed at a reduction of power consumption by the transportation systems (Greune 1989), is carried out all over the world. It concerns, in particular, long, horizontal conveyors and the conveyors operating on inclination.

The electric energy, drawn from the power network by drive motors, is consumed for overcoming differentiated resistances to motion of a belt conveyor. The knowledge about them enables to undertake some activities, limiting the power consumption. These resistances are given in Table 1 (Antoniak 1992). In the case of horizontal conveyors of a medium or big lengths, from 85 to 95 percent of the electric energy, consumed for their operation, is used for overcoming the resistance to motion. A percentile distri–bution of the individual resistances to motion in a heavy-duty, horizontal belt-conveyor of about 1-kilometre length is as follows: indentation rolling resistance – approx. 60%; belt flexure resistance – 5%; material flexure resistance – 18%; roll turning resistance – 6%; secondary resis–tance – 10% and special resistance – 1%.

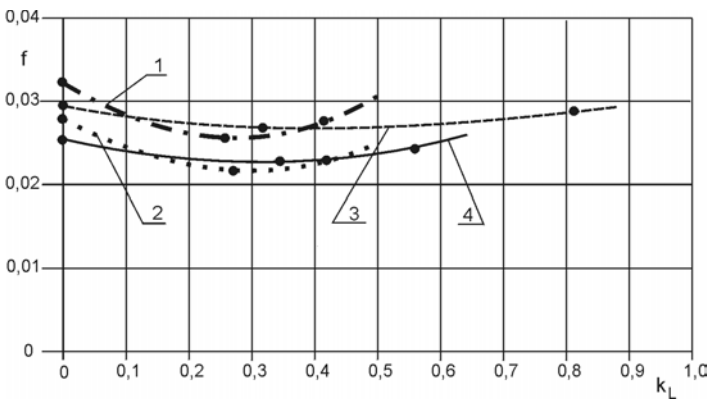

Fig.1. Change of coefficient of primary motion resistances f as a function of conveyor load level k_L; belt conveyor: 1, 2 – PV, PVb B = 1200 mm, v = 3.25 m/s, L = 2158 m; 3 – 3/GX, B = 1000 mm, v = 2.5 m/s, L = 908.5 m; 4 – MP1, B = 1200 mm, v = 3.25 m/s, L = 523.5 m

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Whereas the change primary motion resistance coefficient as a function of conveyor load level is presented on Fig. 1. (the presented results have been gathered from actual mining belt conveyors).

Tab.1. Principal motion resistances of the belt conveyor.

Primary resistances occur along the conveyor's length: • Idler turning resistance from the bearings, grease, and seals • Idler turning resistance from any skew type misalignment • Belt indentation resistance • Belt flexure resistance • Material flexure resistance
Slope resistances: • Due to material being elevated (positive) • Due to material being lowered (negative)
Secondary resistances occur locally around the conveyor: • Loading skirt friction • Loading zone material acceleration forces • Belt bending resistance around the pulleys • Pulley bending and seal resistance • Belt cleaner friction
Special resistances occur locally but not in all designs: • Forward idler tilt • Intermediate loading points • Belt turnover resistance • Material plow resistance

Mathematical relationships describing the main resistances

The main resistances constitute the biggest part of the resistances to motion in the case of long belt conveyors. Their influence decreases in the conveyors operating on an inclination. In the analytical method of elementary resistances the main resistance W_g of the belt conve-yor is expressed by the relationships:

$$W_g = \sum W_{ok} + W_{tt} \qquad \text{N/set}$$

where: W_{ok} – idler turning resistance, N,
W_{tt} – rolling frictional resistance, which is a sum of the belt indentation resistance W_{wg} , belt flexure resistance W_{zt} and material flexure resistance W_{fu}, N.

These resistance are determined for the loaded and return branches of the conveyor.

The idlers' turning resistance is of significant importance as regards a reduction of main resistances and thus ensuring high energy-saving transportation of the run-of-mine. For one idler of known construction, this resistance is the sum of elementary resistances such as: the resistance of idler inertia, idler turning resistance independent from the external load, idler turning resistance dependent on the external load and the turning resistance caused by the idler seal (Lodewijks 1999).

The detailed formulae are given in Table 2.

Tab.2. Mathematical relationships for calculation of the idler resistances to motion.

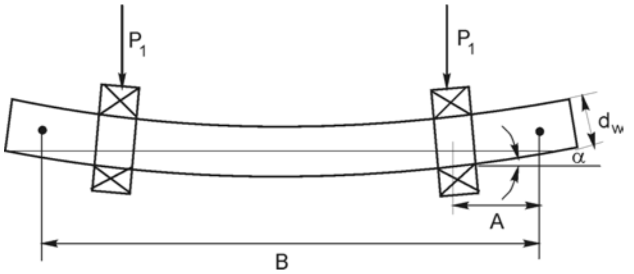
Resistance of idler inertia $W_{ok\,bez} = m_{red} \dfrac{\partial^2 u}{\partial t^2} = \dfrac{1}{2R^2} \cdot \rho \cdot \pi \cdot b_k \cdot \left(R^4 - r^4\right) \cdot \dfrac{\partial^2 u}{\partial t^2}$ N/idler
Turning resistance independent from the external load $W_{ok\,d} = \dfrac{2 \cdot M_o}{R} = \dfrac{2}{R} \cdot 10^{-7} f_o \cdot (\nu \cdot n)^{\frac{2}{3}} \cdot d_{śr}^{3}$ N/idler

Turning resistance dependent on the external load

$$W_{ok\,sz} = \frac{2 \cdot M_1}{R} = \frac{2}{R} \cdot f_1 \cdot P_1 \cdot d_{śr} \qquad \text{N/idler}$$

Turning resistance caused by the idler seal (empirical formula)

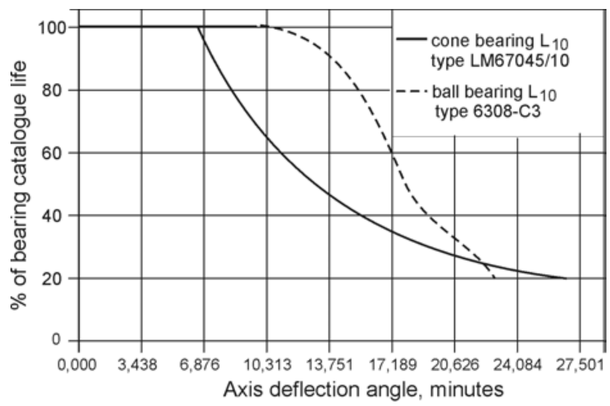
$$W_{ok\,u} = \frac{2 \cdot M_u}{R} = \frac{2}{R} \cdot 10^{-3}\left[\left(\frac{d_w + d_z}{0,02}\right)^2 + 10\right] \qquad \text{N/idler}$$



$$\mathrm{tg}\,\alpha = \frac{P_1 \cdot A \cdot (B - 2A)}{2 \cdot E \cdot I}$$

$I = \frac{\pi}{64} \cdot d_w^4$, cm^4,

E – 2.06 · 10^7 N/cm^2 Young's modulus



$$W_{ok} = W_{ok\,bez} + W_{ok\,d} + W_{ok\,sz} + W_{ok\,u}, \qquad \text{N/idler}$$

Power for overcoming the frictional resistances

$$N_{ok} = 2(M_o + M_1 + M_u) \cdot \frac{n}{9500}, \qquad \text{W}$$

Bearing moment of friction

$$M = M_o + M_1 = \mu \cdot P_w \cdot \frac{d_{śr}}{2}, \qquad \text{N} \cdot \text{mm}$$

$$P_w = \sqrt{P_{pr}^2 + P_{os}^2}, \qquad \text{N} - \text{bearing resultant load}$$

Simplified formulae

$$W_{ok} = a + b \cdot v, \qquad \text{N/idler}$$

$$W_{ok} = (1 + 0.3 \cdot v) \cdot \frac{D}{0.133}, \qquad \text{N/idler}$$

Denotation

- *R, r* – idler external and internal radii, mm,
- b_k – idler width, mm,
- ρ – steel density, kg/mm^3,

$\partial^2 u / \partial t^2$	– belt axial acceleration, mm/s^2,
	$d_{śr} = 0.5(d_w + d_z)$, mm
d_z, d_w	– bearing external and internal diameters, mm,
ν	– kinematics viscosity of lubricating material, mm^{2}s^{-1},
n	– number of revolutions, 1/min,
f_o	– coefficient dependent on the bearing type and lubrication (from 1 to 2),
d_w, d_z, R in the formulae for $W_{ok\,u}$ in m	
f_1	– coefficient $(5 \div 9) \cdot 10^{-4} (P_o / C_o)^{0.55}$,
μ	– coefficient of friction (for radial contact ball bearing with labial or slotted seal from 0.0015 to 0.002),
P_{pr}, P_{os}	– radial and axial forces loading the bearing, N,
C_o	– static basic load capacity, N,
P_o	– bearing equivalent load $(P_o = X_o \cdot P_{pr} + Y_o \cdot P_{os})$, N,
X_o, Y_o	– coefficients given in the tables of bearings,
v	– belt speed, m/s,
D	– idler diameter, m,
a, b	– constants: a = 0.6 to 1.1 N; b = 0.2 to 0.8 N·s/m,
P_1	– idler load, N

Catalogues: FAG; INA; SKF and NSK

Rolling frictional resistance W_{tt} is the sum of idler indentation into the belt W_{wg} and the belt flexure resistance W_{zt} as well as the material flexure resistance W_{fu}, thus

$$W_{tt} = W_{wg} + W_{zt} + W_{fu} \quad \text{N/idler}$$

The resistance of the idler indentation W_{wg} is the sum of resistances, calculated for the centre and side idlers. These resistances decrease in the function of the belt tension and its sag between the idler sets. A general character of the changes of the rolling frictional resistance is shown in Fig.2 (Greune 1989).

This resistance rapidly increases as the load of the idlers increases, which occurs when a changeable amount of the feed, i.e. of the run-of-mine, is directed to the belt. From the graph in Fig. 2 it can be concluded that in the case of a big belt tension a disadvantageous role of the belt indentation resistance increases. The formulae indispensable for calculating the components of the rolling frictional resistance are listed in Table 3 (Spaans 1991).

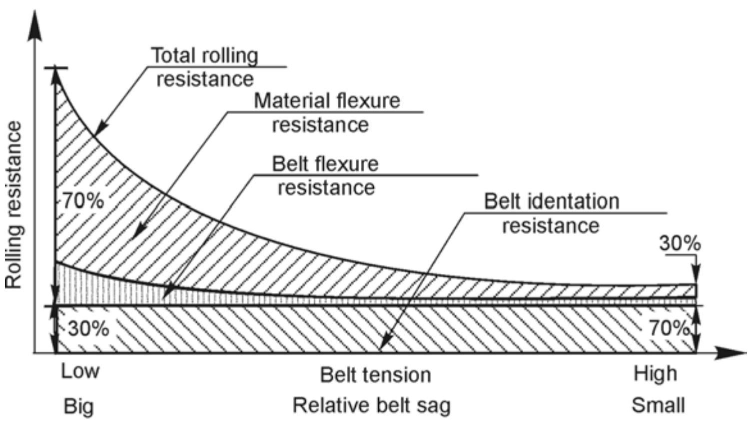


Fig.2. Influence of the belt tension and sag between idlers on the individual main resistance.

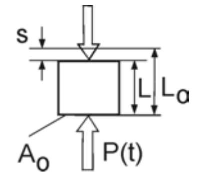
Tab.3. Mathematical relationships for calculation of the individual main resistance.

Belt indentation resistance
$W_{wg} = C_{wg} \cdot D_s^{-2/3} \cdot \left[P_{śr}^{4/3} \cdot l_{śr}^{-1/3} + 2^{7/3} \cdot \frac{3}{7} \cdot P_{bocz}^{4/3} \cdot l_{bocz}^{-1/3} \right]$ N/set
Belt flexure resistance
$W_{zt} = C_{tu} \cdot (m_t + m_u)^2 \cdot g^2 \cdot l^2 \cdot \frac{1}{4T}$ N/set

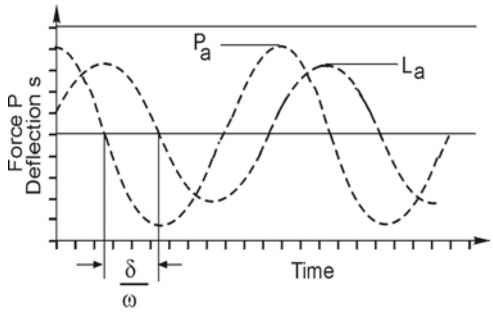
Material flexure resistance

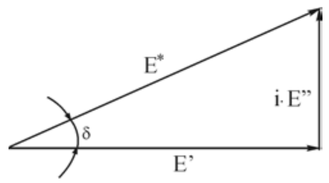
$$W_{fu} = \frac{(m_t + m_u)^2 \cdot g^2 \cdot l^2}{\sqrt{T \cdot EI}} \cdot \frac{4 \sin\phi}{\cos^2\phi} \cdot \frac{d^2}{12l} \quad \text{N/set}$$

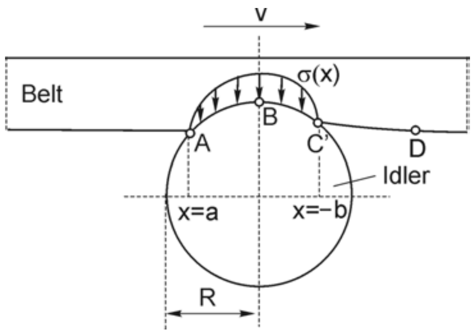
Dynamic tests of elastomers acc. to DIN 53513

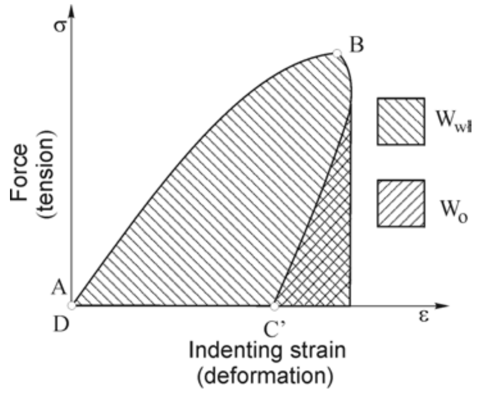


$$\left|E^*\right| = \frac{P_a}{L_a} \cdot \frac{L_o}{A_o}$$







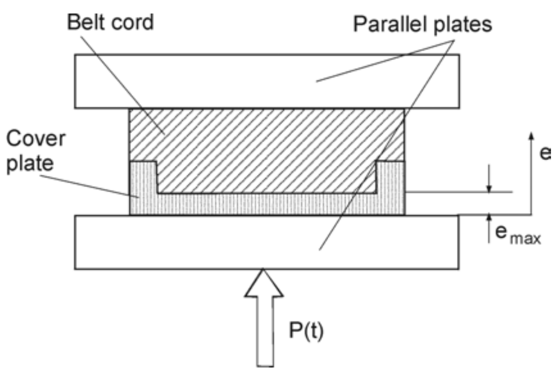


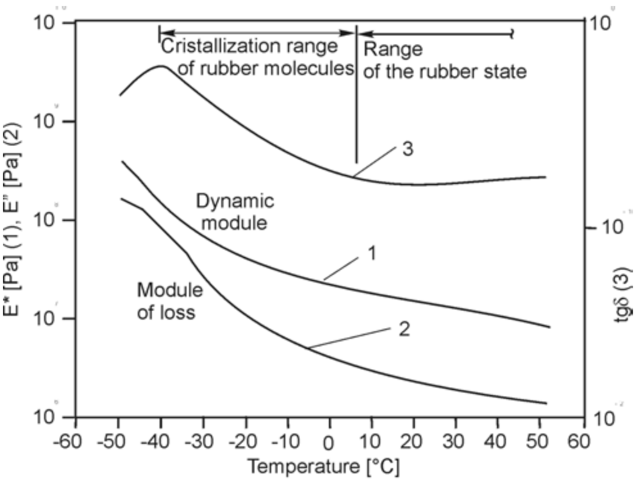
Coefficient of dumping for an indentation

$$\Psi_w = \frac{W_{wł} - W_o}{W_{wł}}$$

Indentation rigidity

$$k_w = \sigma_{max} / e_{max} \quad \text{N/m}^3$$





Viscoelastic properties of the cover plate rubber E*, E" and tgδ in the function of temperature

Denotation

C_{wg} – total coefficient of indentation resistance

$$C_{wg} = \frac{0.5 \cdot \psi_w}{\left(\frac{2}{3}\right)^{4/3} \cdot k_w^{1/3} \cdot \left[1 + (1 - \psi_w)^{3/4}\right]^{4/3}} \quad \text{m/N}$$

D_s – corrected diameter of an idler caused by the belt bend in the area of idler ($1/D_s = 1/D - 1/2\rho$, where ρ – belt bend radius), m, (corrected diameter of the idler D_s depends on idlers' span, belt weight, feed load and belt tension. In most cases $D_s = D$),

$l_{śr}, l_{bocz}$ – length of the contact line between the belt centre and side idlers , m,

$P_{śr}, P_{bocz}$ – normal force on centre and side idlers, N (from the belt and run-of-mine load).

$P(t)$ – sinusoidal load, N,

E'' – module of loss (describes viscoealstic properties), MPa,

E^* – dynamic module of elasticity, MPa,

E' – memory module describes elastic properties of an element (on the real axis), MPa,

δ – deceleration angle in viscoelastic materials ($\delta = 0$ in elastic materials, because the signal tension/deflection is in the phase); δ angle is often replaced by the time δ/ω,

C_{tu} – coefficient of belt bending resistance; $C_{tu} \approx 0.4 \div 0.9$ (most often 0.6),

g – acceleration corresponding to the gravity force , m/s^2,

m_t, m_u – belt and material handled unit weights, kg/m,

ϕ – angle of material handled internal friction, degrees,

d – height of the material handled pile on the belt, m,

l – span of idlers, m,

T – belt tension, N,

$\omega = \sqrt{T / EI}$, m,

EI – belt bending rigidity, N·m^2.

Methods of reducing main resistances to motion

The idler turning resistance W_{ok} can be reduced by decreasing the idler load and the belt speed, correct make of the seal and use of good lubrication of the bearings. However, the correct construction of an idler and its manufacturing technique have the biggest influence on a reduction of the turning resistances. The SKF Company suggests using in the idlers the bearings of increased diameters of balls, which overcome easier the unevenness caused by the contamination of the path.

For the heavy-duty constructions of belt conveyors (of the length > 10 kilometers) it is required (Kahrger and others 2000) that $W_{ok} \leq 2$N without taking into consideration the idler inertia resistance, which is a smaller value than that required by the Polish Standards PN-91/M-46606. The value of this resistance as well as other idler geometrical parameters must be rigorously checked by institutions independent from a producer.

In turn the value of the belt indentation resistance W_{wg} for a given belt type can be reduced by decreasing the force $P_{śr}$ (eg. dividing the load of the centre idler for two idlers) or by increasing the diameter of only the centre idler (most heavily loaded). Thus, it can be assumed that the centre idler in the set with three idlers of the same length bears 70 percent of load, whereas the side idlers – only 15 percent each (Belt conveyors 1997). A belt construction of correctly selected rheological properties plays a big role as regards a reduction of this resistance.

An influence of the belt cover plate thickness, made from synthetic material of low burning properties (SBR – Butadiene-styrene rubber) and of the self-extinguishing properties (CR – chloroprene rubber) on the value of the belt indentation resistance W_{wg} in relation to its width, is shown in Fig. 3.

In the case of the CR cover plate, a reduction of its thickness from 6 to 4 mm causes a decrease of the belt indentation resistance by about 13 percent.

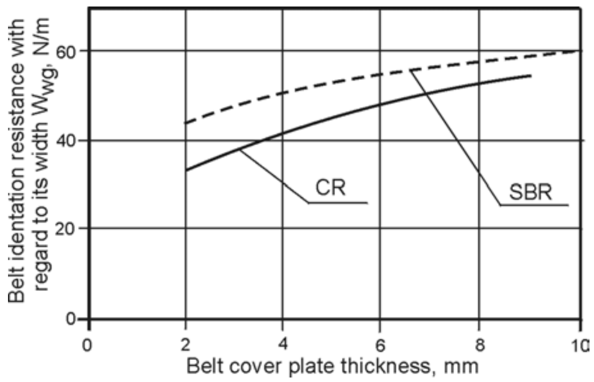


Fig.3. Indentation rolling resistance with respect to belt width W_{wg} as a function of the cover plate thickness; belt speed v = 1 m/s, roll diameter ϕ133 mm, roll load split 5,3 kN/m, belt-heat 20ºC.

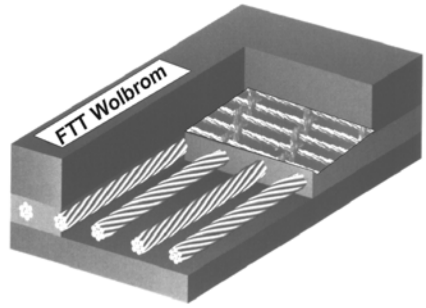


Fig.4. Steel cord conveyor belt with optimized rubber for load- and idler-side cover plates and steel cross reinforcement.

An influence of temperature on the value of the belt indentation resistance with regard to its width, for the same SBR and CR materials used for cover plates is as follows: the higher positive temperatures affect a reduction of the belt indentation resistance in an advantageous way. Many companies, including also the national ones, work on manufacturing special conveyor belts with a cover plate characterized by decreased belt indentation and flexure resistance. An example of such a belt is presented in Fig. 4. It is the GTP ST 3150 belt produced by the FTT Stomil Wolbrom, Joint Stock Company. In the case of a long belt conveyor, in which the cover plate has the chemical and mechanical properties decreasing the rolling frictional resistance, it is advantageous to turn the belt over in the bottom conveyor branch.

A reduction of the value of the belt flexure resistance and the material flexure resistance can be achieved by real or artificial decreasing of the idlers' span l, particularly in the area of small T, by increasing the belt tension T and also by decreasing the value C_{tu} by an optimization of the belt mechanical parameters. An increase of the belt speed v, m/s, affecting a reduction of the m_u value according to the relationship $m_u = Q/3.6 \cdot v$, kg/m, where: Q – mass capacity of the conveyor in t/h, can be essential as well. An increase of the belt speed to 4 m/s and more is recommended for ascending belt conveyors, equipped with the belts with the steel cord. As a result, a smaller value m_u and the belt decreased strength is obtained. A precise determination of the idlers' diameter and their span at the beginning of the conveyor designing process is essential, because these parameters have a big influence on the load, affecting the values of all the unit resistances.

The span of sets should be as big as possible, because the bigger span, the smaller investment and operational costs. A big diameter of idlers and an increased belt tension have a positive influence on decreasing the unit resistances.

A fictitious coefficient of friction f is used in the DIN 22101 method for a determination of the sum of the main frictional resistances occurring jointly in the top and bottom branches of the conveyor, within the limits from 70 to 110 percent of the rated load and keeping the belt sag between the supports of the idlers at the value less than 1 percent. The main resistance W_{gc} in the loaded and return branches are determined by the relationship

$$W_{gc} = f \cdot g \cdot L \cdot \left\lfloor \left(m_u + 2m_t \right) \cdot \cos\beta + q_k^{,} + q_k^{,,} \right\rfloor \quad \text{N}$$

where $q_k^{,}$, $q_k^{,,}$ – weights of rotational parts of idlers in the top and bottom branches, kg/m,

β – average inclination angle of the conveyor in relation to the horizontal level, grad (for $\beta \le 15^{o}$ the value $\cos\beta = 1$ can be introduced)

L – conveyor length, m.

An increase in the belt tension and a reduction of the sag cause a decrease of the value f, similarly to an increase of the idlers' diameter. The value f = 0.020 is regarded to be the standard one and it concerns an installation of the construction made and used in a normal, standard way at the belt speed 5 m/s. As the belt speed decreases the value of the coefficient f decreases as well. At the rated belt load, the coefficient f should be multiplied by the factor c_v (Greune 1989) obtained from the tests, thus $c_v = 0.6 + 0.08 \cdot v$, where v is the belt speed in m/s. Coefficient f depends on the conveyor load level (Fig. 1). For example function f = F (k_L) for the conveyor number 4 is expressed by the following relationship: $f = 0.0144 \cdot k_L^2 - 0.0121 \cdot k_L + 0.0255$.

The biggest value f = 0.035 concerns the conveyors normally operated and conventionally constructed, working in extremely low temperatures.

According to DIN 22101 the standard value *f* = 0.02 should be increased in the following, disadvantageous cases:

- transportation of big internal friction material,
- trough angles > 35^0,
- diameters of idlers < 108 mm,
- belt speed > 5 m/s ,
- belt sag > 1%,
- span of idlers in the carrying branch < 1m,
- belts of thick and soft plates.

It is understandable that the solutions different from the presented ones cause a decrease of the coefficient f value. The DIN Standard does not offer the method for selecting the values, leaving this decision to designers of belt conveyors. All the other resistances to motion , listed in Table 1, should be analyzed in a similar way. The relationships, determining these resistances to motion, given in the appropriate technical literature, can be helpful in this case. Electric energy savings, while changing the values of concentrated resistances in the conveyors of the length up to 100 meters, can be significant, whereas in the conveyors of bigger length they will be small.

Industrial realization of belt conveyors of reduced power consumption and increased life

A reduction of the main resistance in the case of a long belt conveyor, by using special synthetic material for the cover plate in the belt type ST 5400, has been obtained by the Clouth Company. This belt operates together with the sets of idlers presented in Fig. 5 (Graning 2000), installed in the PC-2 tunnel conveyor in the Henderson Mine of molybdenum ore, in the USA. The designers obtained *f* = 0.012 for the empty conveyor and a lower value for the conveyor loaded with the run-of-mine at the belt speed 6.1 m/s and for the belt ST 5400 14T+8T of the width 1.2 meters, using in this belt conveyor all the special technical solutions such as big diameters of the centre rolls in the three-idler sag, idlers of very small turning resistances, the sag angle 30^0, a special belt of a smaller unit weight (the safety factor equals 5) and of small indentation resistances, an optimization of the span of the idlers' sets (a reduction of the number of idlers, sets of idlers installed in the guides with a helical adjusting control. The measurements have shown that this value decreased to *f* = 0.008. In the case of the belt conveyor of the 16.8-kilometre length and the lifting height 471 meters these changes enabled to reduce by 40 percent the value of the fictitious coefficient of friction *f* in relation to its standard value and to use drive motors 4 x 2000 kW for the conveyor of the capacity 2300 t/h of the molybdenum ore. For the coefficient *f* = 0.02 the motors of the total power 10500 kW should be used for driving this conveyor. The present solution of a three-idler arrangement is advantageous in the case of an ascending conveyor.

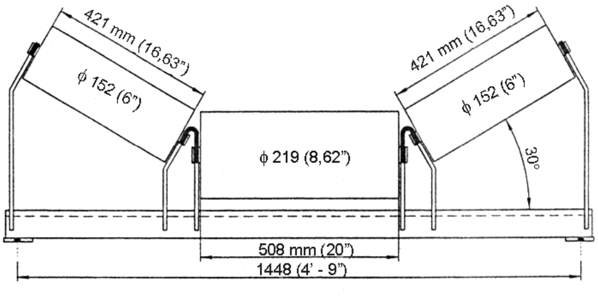


Fig.5. Idler set arrangement in the PC-2 tunnel belt conveyor at the Henderson mine (USA).

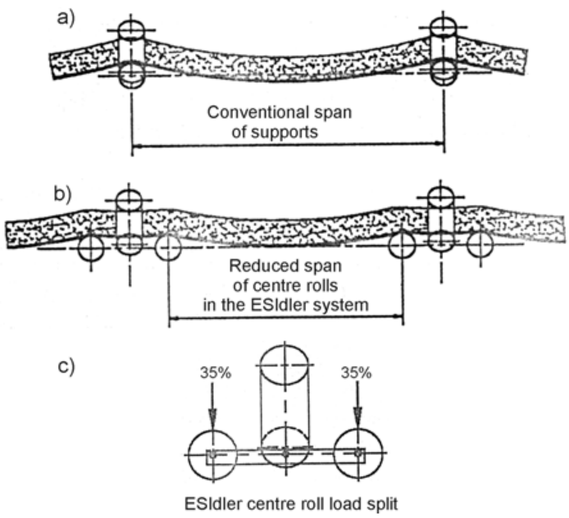


Fig.6. Reduction of belt sag generated by configuration of the idlers in the ESIdler system (Svedala).

Another solution, used more and more often, is the ESIdler (Energy Saving Idler) System of the Svedala company for a four-idler set, Fig. 6 (Tapp 2000).

The sets of this type, in which two centre rolls have a possibility of tilting and adapting to the belt bend, enable to reduce the span of the centre rolls and their load. As a result the rolling frictional resistance decreases in relation to the conventional three-idler arrangements by about 20 ÷ 30 percent. It is a significant reduction in the rolling frictional resistance, which is quite big in the area of a small belt tension and its big sag (in the conveyors of medium length). In the area of a big belt tension and its small sags a reduction of the rolling frictional resistance is smaller and reaches about 8 to 10 percent. An insignificantly increased turning resistance, caused by the fourth idler, is fully compensated by a big reduction of the rolling frictional resistance.

On the basis of theoretical consideration and analyses of the test results, it has been stated that the biggest electric energy savings can be obtained in long, nearly horizontal belt conveyors or in descending conveyors. For an example in the Ziemowit Colliery, in the descending conveyor the drives, controlled by current frequency converters, during the generator operation of motors, convert the obtained energy into the current transmitted to the network. The belt conveyor of the PIOMA 1200 C type, operating in the Ziemowit Colliery (Fig. 7) transmits the power of about 400 kW to the network, when it is loaded at the bottom level. Electric braking with the energy recuperation by the current frequency converter has turned out to be insufficient in certain operational conditions of the conveyor (eg. overloading, switching-off the power supply), which caused overspeeding of the belt and problems with mechanical braking. A significant shortening of the dead time in the operation of brakes and an introduction of an additional hydrodynamic brake (retarder) of the 100-kW power has turned out to be indispensable. This brake, out of necessity, is installed in the area of the discharge return end.

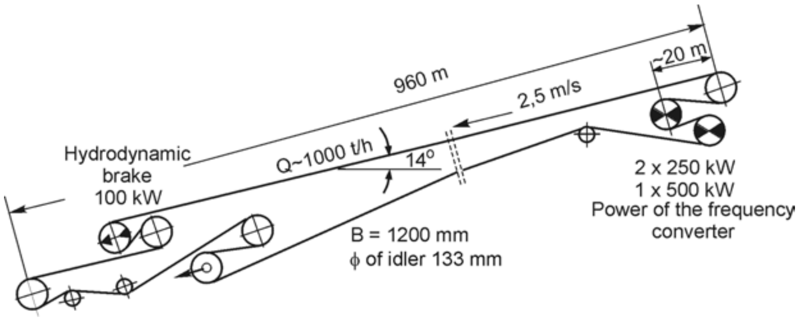


Fig.7. Heavy-duty conveyor of Pioma 1200C type with electric energy recuperation – Ziemowit Colliery.

The hydrodynamic brake converts, without any friction, the kinetic energy into heat. The working medium is oil cooled by industrial water. Due to this solution the brake is well suited for a continuous operation. Certainly in the case of insufficient loading of the conveyor the electric drives must overcome the resistances of the hydrodynamic brake. Due to such a solution an operation of the belt conveyor at such disadvantageous, top parameters has become safe and correct.

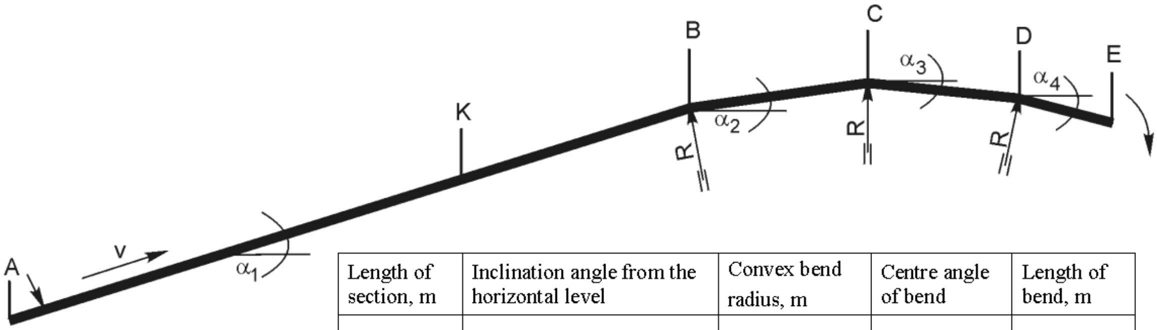
In the case of long, horizontal conveyors there are also additional advantages which include a reduction of the number of drives, discharge areas, electro-technical equipment etc. A trend to increase the length of an individual conveyor (the conveyor of the 2.51-kilometre length is in operation at the Mysłowice Colliery) is fully justified both technically and economically. A significant decrease of the power consumption in the case of the run-of-mine transportation with belt conveyors is also achieved, due to a complete or partial elimination of an askew tilting of the side idlers in the top and bottom idler sets, used for the belt alignment.

A spectacular example of reducing the electric energy consumption, used for overcoming the resistance to the belt alignment in the top branch by about 4000 side idlers with the advance angle up to 4^0 and increasing the life of idlers and conveyors belts, is the horizontal conveyor of the length 2.4 kilometres , installed at the Bogdanka Colliery. After about five months since starting its operation (1994) it has been stated that these idlers caused the wear of about 3.7 tons of rubber from the belt cover plate. After having eliminated an askew position of the side idlers along the whole conveyor and turning over the belt, its life has been increased to such a level that up till the present time (the year 2002), about 19 millions tons of the run-of-mine have been transported by it and it is planned to transport a few more million tons of the run-of-mine till the belt is completely withdrawn from the operation. It should be noticed that at the capacity of 1000 t/h the belt of the GTP 800 type has been installed in this conveyor. A reduction in the power consumption by an elimination of an askew position of the side idlers exceeded 35 kW, which makes about 7 percent of the power, installed for driving the conveyor. A three-fold increase of the idlers' life and a good rectilinearity of the belt in operation has been achieved.

Conveyor belts, produced nowadays at an initial tension, are characterized by their good rectilinearity while running in conveyors. It is required to install the conveyor construction correctly along the axis precisely laid out with the laser method and to ensure a good quality of connections between the belt sections. In justifiable cases special belt centering system can be used (e.g. before its entering on the return drum).

A significant reduction of the power consumption for the run-of-mine transportation is obtained, when current frequency converters for controlling the drives, equipped with induction motors with squirrel-cage rotors, are used. The frequency converter is used for the start-up and a soft control of the rotational speed of the motors in both directions, with an option of braking with the energy recuperation. Due to equipping the system with a programmable microprocessor controller, the frequency converter can be operated in the systems of automatic speed control of the belt conveyors. The converter control system renders it possible to adjust the time of reaching the required rotational speed, the start-up current, braking current, value of overloading limits, type of braking, including the braking with the energy recuperation to the network in the descending conveyors etc., which enables a realization of the soft start and braking of the motor and thus a limitation of mechanical impacts, occurring in the whole driving system and an increase of life of the driving units and of the conveyor itself, a decrease of the starting torque to the value of 1.2 of the rated torque. It also enables an application in the conveyor of the belt of a smaller strength, and thus of a smaller weight. An important advantage of frequency converters is also an equalization of loads between the drives of a given conveyor. Through an adjustment of changeable belt speed v to the current mass stream Q, according to the relationship: $v/v_n = Q/Q_n$, a significantly reduced power requirement for the conveyor drives and thus a reduction of the power consumption for a transportation of the run-of-mine is achieved.

One of the biggest achievements of the present technology is the curvilinear, ascending belt conveyor of the Bogda 1400 type, installed at the Jankowice Colliery (Fig. 8).



Length of section, m	Inclination angle from the horizontal level	Convex bend radius, m	Centre angle of bend	Length of bend, m
AK – 660	$\alpha_1 = 9°50'$			
AB – 894	$\alpha_1 = 9°50'$			
BC – 75	$\alpha_2 = 4°55'$	B – 200	4°55′	17.140
CD – 63	$\alpha_3 = 1°47'$	C – 200	4°55′	17.140
DE – 38	$\alpha_4 = 7°06'$	D – 200	5°06′	19.52

Fig.8. Geometry of the curvilinear, ascending belt conveyor of the Bogda 1400 type.

In the middle of its length (point K, Fig. 8) this conveyor has a spatial bend. It is essential that in this area significant tension forces occur in the belt, which require special calculations, concerning the belt stability and an application of a complex procedure of selecting idlers' sets, guiding the belt along the bend.

Due to this arrangement the conveyor is unique in worldwide. The state-of-the-art supporting structure of the Bogda 1400 conveyor, which is not equipped with the side idlers with advance, but has 17 self-guiding supports in the top branch and 17 self-guiding elements in the bottom branch, situated every 60 meters. It is also equipped with 20 percent of the top idlers and 70 percent of the bottom idlers of a reinforced construction because of a significant unit weight of the belt with the steel cord of the GTP ST 3150 type, in which the metal mesh is installed in the top plate every 30 meters to protect the belt against longitudinal cuts. Multi-drum drives with motors, situated only at one side of the conveyor, are a Polish specialty. This solution, implemented due to using the current frequency converters for controlling the asynchronous motors, has many advantages such as: a small cubature of working is required in the area of the drives, an easy installation of the overhead crane servicing the drives, a possibility of installing the drives and all the accompanying equipment in one place, which has reduced the investment and operational costs.

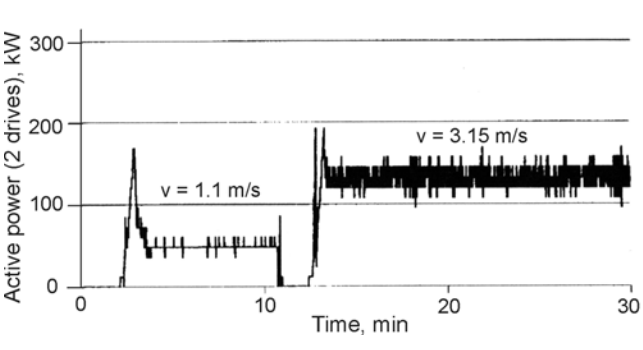


Fig.9. Active power of two conveyor drives measured for unloaded conveyor type Bogda 1400.

However, the biggest achievement, obtained as a result of a sophisticated construction of the belt and the Bogda 1400 conveyor, is a decrease of the fictitious coefficient of friction, used in the DIN 22101 method for calculating the conveyor resistance to motion, whose standard value is accepted as f = 0.020.

In October 2002 some measurements of the active power of two conveyor motors, supplied from the field No. 8 of the switching station R11 were taken. It was assumed that the results of measurements in a form of an oscillogram are identical also in the case of the other two motors, supplied from the field No. 9. The following instrumentation was used for taking measurements: the MSPa 12 transducer of active power, the SRC-8 recorder and the CA6100 computer notebook. The measurements were taken for the conveyor, which was not loaded with the run-of-mine, at the belt speed of 1.1 m/s and 3.15 m/s (Fig. 9).

Using the technical data of the belt conveyor and of the belt as well as the data from the measurements of the active power, the value of the fictitious coefficient of friction was determined and for v = 1.1 m/s it equals f = 0.011 and for v = 3.15 m/s – f = 0.018. Such exceptionally small resistances to motion mainly result from a special construction of the GTP ST 3150 belt (Fig. 4) of very small indentation resistances into the idlers. This belt, with a steel cord, has a spacer in the cover plate, made of the Fleximat metal mesh. The rubber of the CR type (chloroprene) was used for a construction of the appropriate thickness plates. Small resistances to motion in the case of the Bogda 1400 conveyor result also from small turning resistances of the idlers (which were subjected to separate tests), lack of the side idlers with an advance, big tension forces transmitted by the belt, which affect a reduction of the belt flexure resistance and the material flexure resistance, good operational conditions and an application of the drives with frequency converters. The tests proved that savings of the electric energy reached on average 0.55 kWh/t. Up till the present time about 4 million tons of the run-of-mine have been transported by this conveyor.

One of the ways of reducing the power consumption, while transporting the run-of-mine, includes an application of a changeable span of idlers in a long conveyor, which increases towards an increase of the belt tension. An additional advantage of this solution is a reduction of the purchase and installation costs of the conveyor. Special optimization programmers can be helpful in selecting the spans between sets.

A proper positioning of the conveyor and ensuring its proper operation (cleanness of the conveyor, an exchange of idlers and the belt cleaning equipment, a check-up of connections etc.), a correct construction of the discharge areas, an appropriate initial belt tensioning etc. should be among regular technical activities, connected with the energy saving in the process of the run-of-mine transportation.

In the case of the belt conveyors of a special configuration (horizontally descending), sometimes it is not necessary to reduce but to increase the resistances to motion, so that to reduce the power of motors, operating simultaneously in the motor and generator system as well as to protect the belt against falling out from the discharge drum, while braking the conveyor (Antoniak 1999). In this case the DIN 22101 Standard, indicating the condition, in which the value of the fictitious coefficient of friction f increases, should also be used.

Final conclusions

The problem of energy savings has not only the economic dimension, but also the dimension of the widely understood environmental protection, connected with the fact that for a smaller amount of the generated electric energy, the emissions to the atmosphere of so called green-house gases are limited and smaller as well. As it has been shown in the previous chapters there are big possibilities of reducing the power consumption by the run-of-mine transportation systems in the underground hard coal mines. After a period of a spontaneous introduction of belt conveyors for the transportation of the run-of-mine, instead of the mine railway systems and in justifiable cases instead of the hoisting installations as well as after a systematic reduction of the length of the conveyor transportation systems, at present, it is indispensable to furnish the belt conveyors with technical solutions, resulting in a reduction of the power consumption for transportation of the run-of-mine. When the power consumption for transportation of the run-of-mine decreases, the wear of the conveyor assemblies and elements decreases as well. This relationship has been shown on the basis of the examples of the concrete, industrial technical implementations.

The theoretical foundation, presented in the paper and the technical activities, started by some mines, aimed at a reduction of the power consumption in the run-of-mine transportation process, are disseminated and enhanced by creative activities of the engineering staff in the mines and enterprises, dealing with designing and production of conveyor belts, idlers, electro-technical systems and other elements of a belt conveyor construction.

From many different technical activities, reducing the energy consumption for the run-of-mine transportation, the following actions should be mentioned:

- keeping the rectilinearly and cleanness of the conveyor path,
- a simplification of transportation systems, an elongation of conveyors,
- correct design of discharge areas and a reduction of their number,
- an application of special idler systems and an optimization of the span of idlers' sets,
- a construction of belts of differentiated plates – load-carrying one resistant to abrasive wear, the bottom one of reduced rolling frictional resistances,
- a more frequent introduction of the drives, controlled by current frequency converters, enabling to control the belt speed and recuperate the energy in the case of horizontal conveyors, in particular descending ones.

The examples of some technical implementations, ensuring energy saving transportation of the run-of-mine and an increase of the belt conveyor life, presented in the paper, are in a more and more complete manner adapted to the conditions of the Polish hard coal mines.

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