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energy-saving mine belt conveyor, realizations in Polish collieries

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# ENERGY-SAVING BELT CONVEYORS INSTALLED IN POLISH COLLIERIES

**Summary.** An important problem of reducing energy consumption and dioxide emissions in the stage of construction and operation of mine belt conveyors is connected with their broad use in the industry. However, this notion is related to a reduction of electric energy consumption for conveyor drive and for production of conveyor components and assemblies (belts, rollers, load-bearing structure etc.). An essential role is played by an increased life of belt conveyors assemblies and components, principally belts. A reduced electric energy consumption results in a decreased $CO_2$ emissions, e.g. hard coal – fired power station issues 0.28 kg $CO_2$ per production of 1 kWh, in to answer production of 1 t steel accounts for 3.2 t $CO_2$ emissions. The subject-matter presented in the paper concerning energy-saving in the horizontally and inclined mine belt conveyors installed in a Polish colliery – Anna, Jankowice and Marcel, has a big economic significance and it is important from the point of view of environmental protection.

# ENERGOOSZCZĘDNE PRZENOŚNIKI TAŚMOWE ZAINSTALOWANE W POLSKICH KOPALNIACH PODZIEMNYCH

**Streszczenie.** Z szerokim zastosowaniem w kopalniach podziemnych węgla kamiennego przenośników taśmowych związany jest ważny problem zmniejszenia energochłonności i emisji $CO_2$ w ich budowie i eksploatacji. Przy czym pod tym pojęciem rozumie się zmniejszenie ilości energii elektrycznej zużywanej do napędu przenośników taśmowych oraz wykorzystywanej energii elektrycznej do wytwarzania elementów i zespołów przenośnika (taśm, krążników, konstrukcji nośnej itd.). Istotne znaczenie ma także zwiększona trwałość zespołów i elementów przenośnika taśmowego, szczególnie taśmy. Mniejsze zużycie energii elektrycznej skutkuje mniejszą emisją $CO_2$, przykładowo elektrownia opalana węglem kamiennym emituje 0,28 kg $CO_2$ na wyprodukowanie energii 1 kWh, produkcji 1 t stali odpowiada emisja 3,2 t $CO_2$. Przedstawiona w pracy problematyka dotyczy energo-oszczędnych poziomych i wznoszących przenośników taśmowych zainstalowanych w polskich kopalniach – Anna, Jankowice i Marcel – i ma duże znaczenie ekonomiczne oraz w ochronie środowiska naturalnego.

## 1. ENERGY-SAVING MINE BELT CONVEYORS UNDER ANALYSIS

A problem of energy-saving in the case of belt conveyors will be presented in literature [1-3]. We can describe it on the base of three conveyors – one installed in the Anna Colliery, the second one operating at the Jankowice Colliery and the third one – at the Marcel Colliery. The technical specification of the conveyors is given in Tab. 1.

Table 1

Technical specification of energy-saving mine belt conveyors

| Conveyor | | Belt | | Power of driver kW | Use of transverse inter-section % | Power discrimi-nate kW/m | Bends | | |
|---|---|---|---|---|---|---|---|---|---|
| Length, m Place of installation | Productivity t/h Transportation height, m | *B*, m type | *v*, m/s | | | | *R* m | Number | |
| | | | | | | | | Hor. | Vert. |
| 850 Gwarek 1400 Anna Colliery | 2100 0 | 1.4 PVG 1250 | 0,5 2,5 | 2x132* | 30 to 48 | 0.311 | – | – | – |
| 1080 Jankowice Colliery | 2000 +151 | 1.4 ST 3150 | 1.6 3.8 | 4x355** | 56 | 1.315 | 600♦ | 1 | 3 |
| 1860 Marcel Colliery | 1500 +385 | 1.4 ST 4500 | up to 4.2 | 3x860*** | 35 to 46 | 1.387 | – | – | – |

♦spatial arc; *, ** squirrel – cage motor controlled by current frequency converter of PPC-2 type, of PPC 2/3 (1000 V); *** squirrel – cage motor controlled by voltage frequency converter (ABB), 690 V

## 2. ENERGY-SAVING BELT CONVEYOR IN THE ANNA COLLIERY

A state-of-the-art belt conveyor of Gwarek 1400 type (Tab. 1) was installed in the Anna Colliery in 1996. The control of belt conveyors‘ operation was performed in the PS2010 PROMOS system, using breakers of Hamacher type. A control of speed (from 0.5 to 2.5 m/s) and of belt acceleration (Fig. 1) of the receiving conveyor was realized in the function of supplying conveyor belt filling with the run-of-mine (thickness of stream). This control can be extended for a bigger number of feeding conveyors. The thickness of the run-of-mine stream is determined with an ultrasonic sensor. All the data concerning an operation of belt conveyors are recorded and displayed on monitors in the mine control room on the surface.

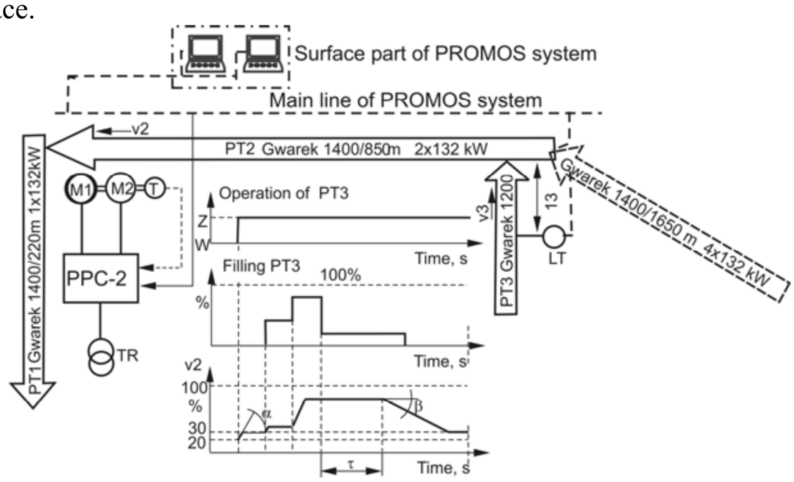



Fig. 1. Structure of belt conveyor automatic speed control with a frequency converter as well as with an example of belt speed control in the function of the feeding conveyor filling Ml, M2, T, PPC-2, TR, LT – driving motors, tachogenerator, frequency converter, transformer, ultrasonic measurement sensor; a, b – ramp angle of acceleration and deceleration of the receiving conveyor; t – time of run-of-mine haulage on the supplying conveyor from the measurement point to the discharge point, t=13/v3

Rys. 1. Schemat przenośnika taśmowego w kopalni Anna z automatyczną regulacją prędkości taśmy

The advantages resulting from using frequency converters are: an elimination of high start-up torques, a minimization of dynamic loads of belt and drive systems, a reduction of generated heat, an elimination of field bunkers, an elimination of composed brake systems and a reduction of operational costs, but in particular an extension of drive systems' life and a reduction of belt friction wear.

Functional possibilities of PPC-2 converter include a broad scope of belt speed and acceleration control, auto-diagnostics, multi-outflow equipment, a full electric protection of motors, extended operational connecting components, a possibility of conveyor electric breaking with the energy recuperation to the grid, a possibility of collaborating with any control system and operation in the "by-pass" mode, as well as possibility of a remote reading of drive parameters and also a possibility of using in the conveyor the belt of lower strength and thus smaller unit weight.

A significant reduction of power consumption for a horizontal conveyor drive and thus a reduction of the energy consumption for the run-of-mine is obtained due to an adaptation of variable belt conveyor speed to current mass stream Q, according to the relationship: v/vn=Q/Qn. According to the measurements taken on this belt conveyor it has been determined that the annual profit (1996/1997) on the electric energy cost reached about 0.9 Mio zloty. At the cost of 1 kWh of about 0.12 zloty in that period, annual savings on electric energy consumption were 7.5 Mio kWh and they caused a reduction in the power plant emissions of about 2100 t $CO_2$/year. These savings for 1t of the transported run-of-mine were 7.5 Mio kWh/2.95 Mio t of run-of-mine=2.54 kWh/t.

An energy-saving feature of this belt conveyor results from an extended life of the PVG 1250 (solid woven) belt, which transported 28 Mio tons of the run-of-mine till the end of 2005, an extended life of belt load-bearing assemblies, a reduced consumption of electric energy for a conveyor drive, for braking the conveyor with energy recuperation to the power and electric grid and nearly arithmetical load distribution on both drive motors. The described belt conveyor situated on the level – 1000 m will be operated till 2011.

## 3. ENERGY-SAVING BELT CONVEYOR AT JANKOWICE COLLIERY

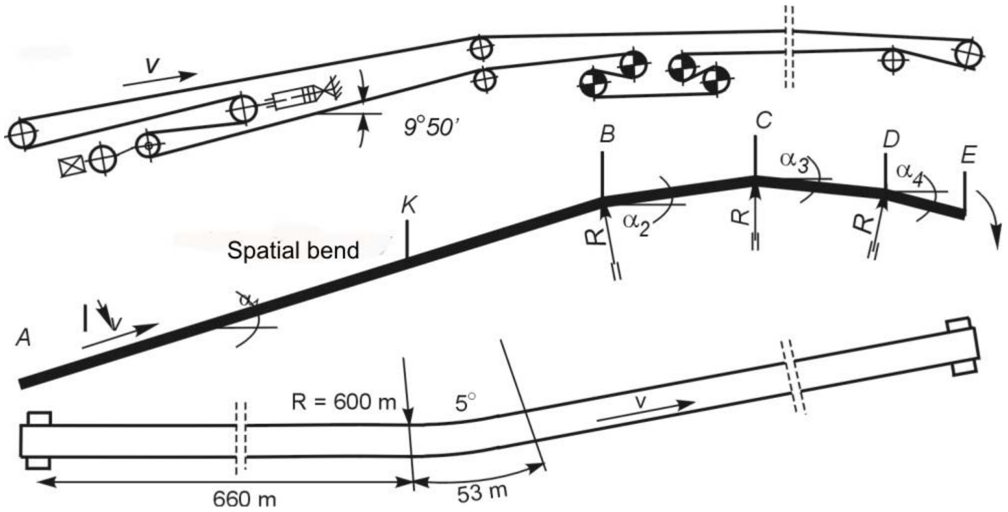
Energy-saving arterial inclined and inter-level belt conveyor with a spatial curvature, installed in the incline of the Jankowice Colliery, has four single drum drives.

An operation of converters in the Bogda 1400 conveyor and of its electric equipment is supervised by a microprocessor control system of Betacontrol type. A supervision of equalization of torques in the whole driving system is performed by a microprocessor controller of the converter No.2, which is treated as master for other converters. An equalization of torques among converters is realized through conductors with appropriate torque controllers. An algorithm of the conveyor operation has been developed to make the belt speed related to the amount of the run-of-mine transported by the feeding conveyor. The measurement of the run-of-mine amount is supervised by a controller with two ultrasonic sensors.

The belt speed, changed in relation to the amount of the run-of-mine on the belt, varies from 1.6 to 3.8 m/s. The conveyor (Fig. 2) is equipped with anti-return couplings and hydraulic brake sets, which are supplied from a hydraulic power-pack. It is also equipped with an automatic tensioning station, situated near its return-end. The colliery, installing this belt conveyor, approved of the concept and calculations, made by the Author, which concerned a unique, in the world scale inclined conveyor with a spatial bend.

The belt ST 3150-10/8 with a breaker made of steel mesh in the load-bearing cover (made by FTT Wolbrom J.S.C.) of the width 1.4 m was installed in the conveyor [4]. The belt covers were made of material on the base of chloroprene caoutchouc. For the production rate of 2000 t/h a use of nominal transverse intersection of handled material on the belt is 56%. The power of drive motors for this production rate reaches 1100 kW, which accounts for 77.5% of installed power.

Such a small power consumption for a drive results from small values of the fictitious coefficient of friction f, which on the base of measurements and calculations for the belt speed of 1.1 m/s is 0.011 and for 3.15 m/s – 0.018. During the top period when the production rate was 3000 t/h and the belt speed was 3.8 m/s, the power of drive motors reached 1600 kW. An overflow of the rated power was about 13%.




| Length of section, m | Inclination angle to horizon | Convex bend radius, m | Bend middle angle | 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′ | 17.14 |
| CD – 63 | $\alpha_3 = 1°47'$ | C – 200 | 4°55′ | 17.14 |
| DE – 38 | $\alpha_4 = 7°06'$ | D – 200 | 5°06′ | 19.52 |

Fig. 2. Schematic diagram of inclined belt conveyor of Bogda 1400 type with spatial bend in Jankowice Colliery
Rys. 2. Schemat przenośnika taśmowego wznoszącego typu Bogda 1400 z łukiem przestrzennym (KWK Jankowice)

The energy-saving feature of this conveyor results from: a use of motors controlled by current frequency converters which contribute to nearly arithmetic distribution of load on individual driving drums [5, 6]; small values of fictitious coefficient of friction due to 50% filling with the run-of-mine of the nominal intersection meant (acc. To standards) for a construction of a handled material heap, which contributes to a reduction of the rolling resistance at denting (Fig. 3) and continually increasing belt tensioning force, causing a quick decrease in the belt deflection (which in the lift range of about 18 m is already smaller by 1%), in the result of which the belt inflection resistances and the run-of-mine undulation resistances decrease significantly; the belt with the steel cord, the breaker and the running cover made of the material based on chloroprene caoutchouc of a reduced rolling friction resistance at denting (in the temperature of about 25°C) a use of sets of rollers of 133-mm dia, an inclination of side rollers 35° and their spacing 1.5 m; a transportation of the run-of-mine of relatively small internal friction; an increased belt life (Tab. 2), which results among others, from soft starts and braking of the conveyor, a change of the belt speed in the function of the amount of the run-of-mine on the belt, a correct rectilinearity, a proper construction of vertical bends and of the spatial bend, a reduced consumption of electric energy for the conveyor drive (according to tests an average reduction was 0.55 kWh/t of handled run-of-mine, which during the period of the belt life gave about 9.6 million kWh and a reduction of 2690 t $CO_2$ emissions, by power plants.

Table 2

Life of GTP ST 3150-10/8 belt operating in Jankowice Colliery

| Amount of handled run-of-mine, Mio tons | Belt operational period, years | Janko of performed cycles | Belt conveyor | | | |
|---|---|---|---|---|---|---|
| | | | type of drive | length m | power kW | belt speed m/s |
| ~ 16.0 | 7.5 | about 227 000 | Bogda | 1080 | 4x1x355 | 1.6÷3.8 |

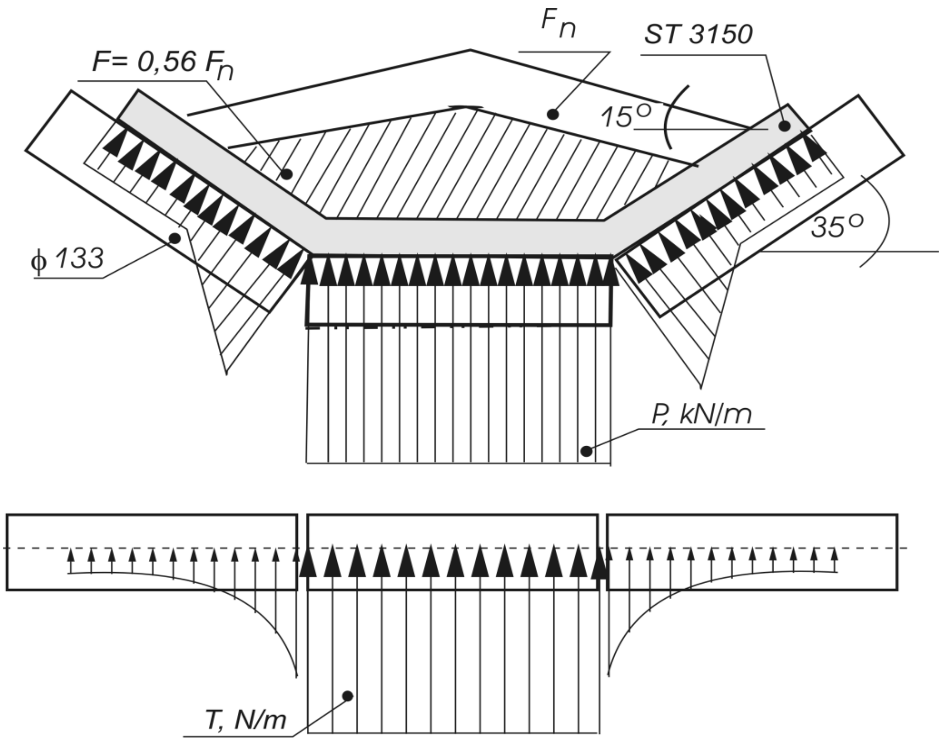



Fig. 3. Distribution of the vertical load on the rollers set and distribution of rolling friction resistance by 56% use of the nominal transverse intersection and for belt bottom covers made of chloroprene rubber (Jankowice Colliery)

Rys. 3. Obciążenie zestawu krążnikowego siłami pionowymi *P*, kN/m i odpowiadający im rozkład siły tarcia toczenia przy wgniataniu *T*, N/m (kopalnia Jankowie)

## 4. MARCEL COLLIERY – ENERGY-SAVING MINE BELT CONVEYOR IN TRANSPORT INCLINE FROM THE LEVEL – 400 M TO THE SURFACE

A state-of-the-art belt conveyor was implemented in the Marcel Colliery in March 2008 for handling the run-of-mine in the amount of about 10 000 t/d (maximally 1500 t/h) using a transport incline from the level -400 m in the marklowicka part to the surface, to the coal preparation plant. Annually 2 mio tons of coal net at impurities from 20 to 25% are handled by this conveyor. In this area three longwall faces are in operation (in 2010, one of them has a production rate from 6000 to 8000 t/d). After the year 2018 till the year 2034 the annual production will increase to 2.5 Mio tons net at average impurities of 23%. The belt conveyor will handle about 12 500 t/d. Marcel run-of-mine conveying is one of the most advanced systems of its type in Europe.

In the first 24 months of exploitation the belt conveyor handled failure-free 5.266 million t run-of-mine. A conceptional design project of the arterial inclined belt conveyor and of its mechatronic systems (automation, control and visualization) has been elaborated by the Author [7] in collaboration with prof. A. Lutyński. The new conveying system of run-of-mine at Marcel Colliery makes mining operations more flexible and helps considerably cut the overall operating costs.

An important step towards a colliery of the future is an inclined, remotely controlled belt conveyor which started its operation in the Marcel Colliery in 2008. It has an integrated supply, control and visualization system. The haulage and transport incline in the Marcel Colliery together with electrical and mechanical equipment form the basic component of a new model of a colliery production system. The components operating in the technical system of the incline are given in Tab. 3.

Denotations of the conveyors correspond to those in Fig.4. The basic criterion of the control algorithm is a control of the run-of-mine flow rate in the future aspect of energy-saving on the run-of-mine haulage. An operation of the whole haulage system in the haulage and transport incline is supervised by a central controller IPC Mining Master (made by Becker-Warkop Company) to which the voltage frequency converters of PT2 conveyor, Mincos controller and local controllers BFS of the conveyors: PT1, PT2 and PT3 are subordinated. It also communicates with the conveyor controller in the mine control room to send information to a process of visualization and data recording.

Table 3

Technical specification of equipment installed in the haulage and transport incline in Marcel Colliery

| Name | Length m | Inclination grades | Drive power kW | Lifting height m | Speed m/s | Capacity $m^3$ |
|---|---|---|---|---|---|---|
| Retention bunker Z | – | – | – | – | | 700 |
| Scraper PZ1<br>feeders PZ2 | 7<br>7 | 0<br>0 | $60^{x}$<br>$60^{x}$ | –<br>– | 0.1 ÷ 0.9<br>0.1 ÷ 0.9 | – |
| Belt conveyor PT3 | 850 | 0 | $2\times250^{xxx}$ | | 3 | – |
| Belt conveyor PT2 | 1860 | 12 | $3\times860^{xx}$ | 385 | 0 ÷ 4.2 | – |
| Belt conveyor PT1 | 110 | 12 | $2\times160^{xxx}$ | 20.6 | 3.2 | – |

$^{x}$ – motors controlled with current frequency converter (1000 V)
$^{xx}$ – motors controlled with voltage frequency converter (690 V)
$^{xxx}$ – drives with hydrodynamic couplings Voith-Turbo

The underground central controller Mincos communicates with the BFS controller of scraper conveyors PZ1 and PZ2, with radar meter in the banker and with scales of the controller PT3. The on-line supervision system of the equipment installed in the incline, under discussion, is characterized by many advantages: flexibility of the run-of-mine haulage, availability, reduction of operational costs (including energy-saving), increase of safety, reduced number of operators and others.

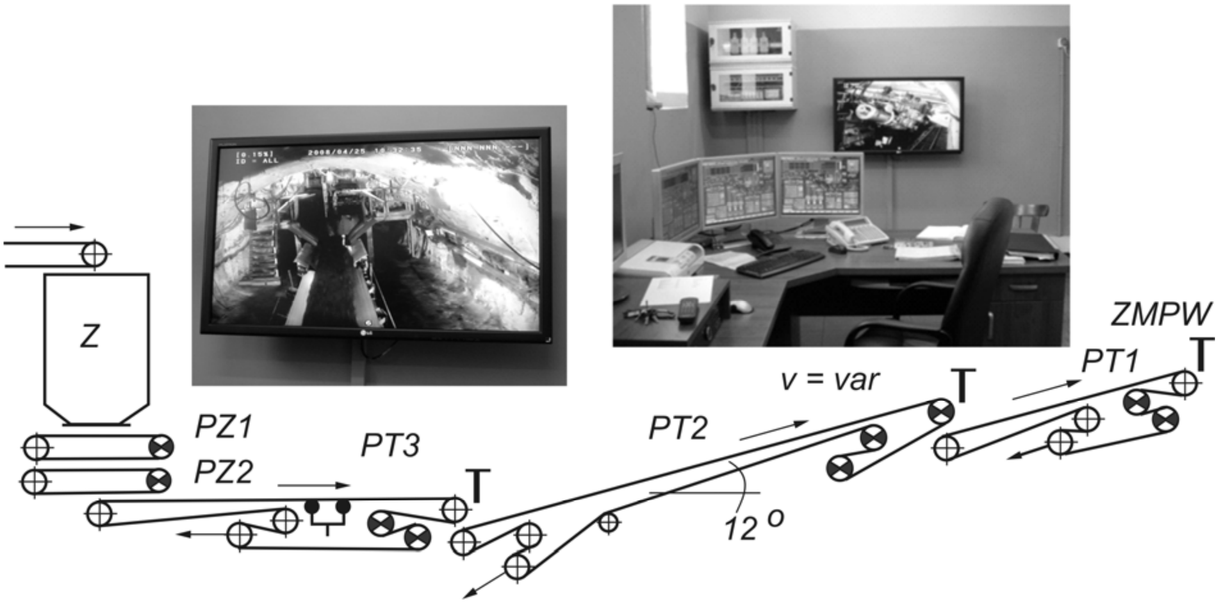



Fig. 4. Schematic diagram of the belt conveyors PT1, PT2, PT3 and of scraper conveyors PZ1, PZ2 installed in the haulage – transport incline in the Marcel Colliery with a view of power-mechanical mine control room and a film camera over the discharge from TP3 to TP2 (ZMPW – Zakład Mechanicznej Przeróbki Węgla – Coal Mechanical Preparation Plant)

Rys. 4. Schemat przenośnika taśmowego wznoszącego wraz z wyposażeniem w układy sterujące, automatyki i wizualizacji (KWK Marcel, 2008)

Using the data recorded in the power-mechanical mine control room (Fig. 5), coming from dozens of mechatronic sensors installed in sore points of the conveyor, the values of some conveyor parameters have been determined (Tab. 4).

Table 4

Determined values of fictitious coefficient of friction *f* for belt conveyor Pioma 1400

| Condition of belt conveyor loading t/h | Belt speed m/s | Unit weight of run-of-mine on belt kg/m | Power of drives kW | Filling of cross-section with run-of-mine on belt % | Accepted coefficient of length C (-) | Fictitious coefficient of friction *f* (-) |
|---|---|---|---|---|---|---|
| empty | 2.9 | 0 | 3x143.3 | 0 | 1.01 | 0.016 |
| with run-of-mine 1050 | 2.9 | 100 | 3x524.7 | 36.0 | 1.053 | 0.012 |
| with run-of-mine 1210 | 3.314 | 101.5 | 3x593.3 | 41.2 | 1.053 | 0.0145 |
| with run-of-mine 1500 | 3.5 | 119 | 3x685 | 45 | 1.053 | 0.015 |

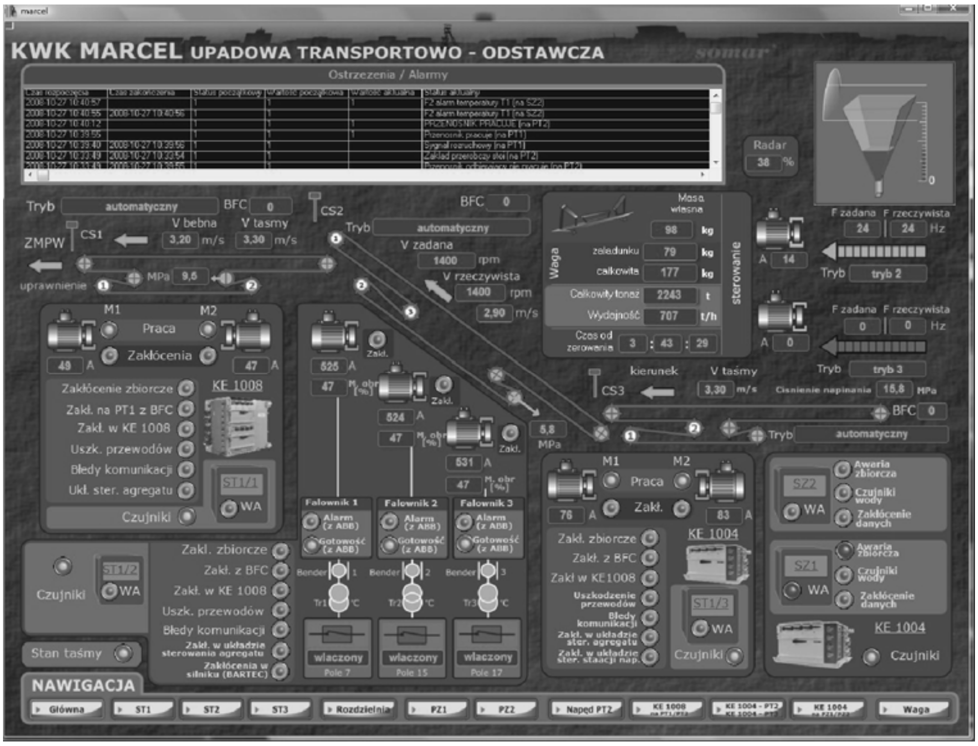



Fig. 5. Module TRANSPORT in mine control room in Marcel Colliery
Rys. 5. Moduł „transport" na tablicy w dyspozytorni energomechanicznej (KWK Marcel, PUiP Somar)

Basing on the obtained values of coefficient *f* the graph has been made (Fig. 6). Efficiencies of the system; motor – voltage frequency converter – gear – efficiency of driving drum [6] have a strong impact on the data given in Tab. 4. In the system, under discussion, the relationship occurs: $v = n \cdot v_{nom}/n_{nom}$, m/s, where *v*, *n* – changed belt speed and motor rotations. Index nom is nominal velocity.

By increasing the speed at a given belt conveyor production rate *Q*, t/h, a reduction of power need in kWh for a haulage of 1 t of the run-of-mine is obtained. It results from a reduction of the unit weight of the run-of-mine on the belt $m_u = Q/3{,}6 \cdot v$, kg/m, and thus also a reduction of the run-of-mine lifting resistance $W_H = g \cdot m_u \cdot H$, N.

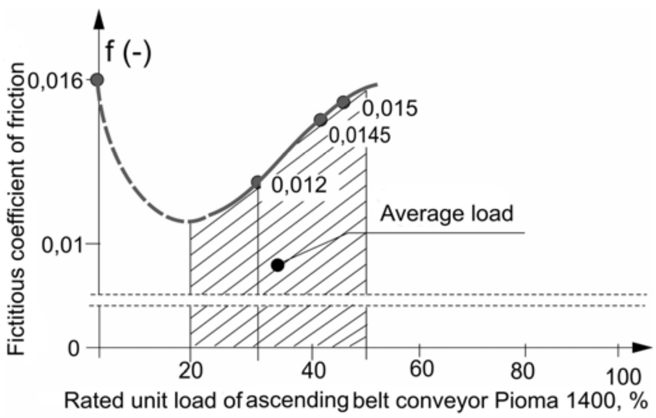



Fig. 6. Coefficient *f* in the function of rated load of ascending conveyor Pioma 1400 in the Marcel Colliery
Rys. 6. Współczynnik *f* w funkcji procentowego obciążenia przenośnika wznoszącego typu Pioma 1400 (kopalnia Marcel)

It can be shown that for example increasing the belt speed by 10% in relation to the rated *v*, a nearly identical percentage reduction of the power need (Fig. 7) in kWh, thus a reduction of carbon dioxide emission by about 0.28 kg in the power plant) for a haulage of 1 t of the run-of-mine, is obtained.

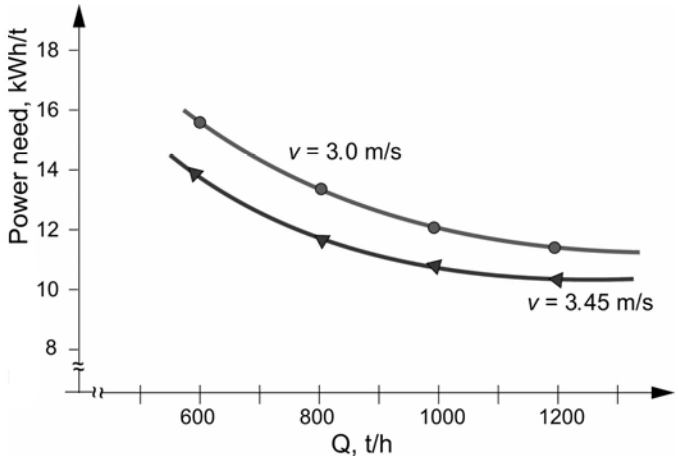



Fig. 7. Need of energy for a haulage of 1 t of the run-of-mine in the function of the conveyor production rate for a belt speed parameter (belt conveyor Pioma 1400, Marcel Colliery)

Rys. 7. Zużycie energii na odstawę 1 t urobku w przenośniku wznoszącym w funkcji wydajności *Q*, t/h dla parametru prędkości taśmy (przenośnik Pioma 1400, kopalnia Marcel)

A cost of driving a transport working and equipping it with a belt conveyor and toothed floor-mounted railway for a transportation of materials and personnel was 90 Mio PLN and it was a dozen or so times lower than the costs which would have been borne if a new vertical production shaft had been constructed and a few times lower if two belt conveyors instead of one had been used in the incline.

An energy-saving advantage of a long, inclined mine conveyor in the Marcel Colliery results from: a very elastic run-of-mine conveying system; a use of voltage frequency converters for controlling the motors of high power, ensuring among others an arithmetical distribution of load on individual motors and a control of the belt speed and with system of continuous belt tension assures long life of belt; a small belt speed lengthening time of the belt cycle and its life; a small filling of the transverse intersection of the run-of-mine heap on the belt (from 0 to 54%), which has an impact on a reduction of the fictitious coefficient of friction f (acc. to DIN 22101); continually increasing belt tension from the dumping return end to the discharge drive, due to which a belt sag among sets of rollers (a value of this sag varies from several-thousandth to ten-thousandth metre) quickly decreases and in the result the resistances of the belt contraflexure as well as the run-of-mine undulation resistances, which are incorporated in the fictitious coefficient of friction f, decrease; optimized constant filling belt conveyor with run-of-mine (controlled discharge from the bunker); a limited number of the belt contraflexures on driving and other drums; a sophisticated implementation of mechatronic systems for an operation and exploitation of the conveyor, in particular for controlling the belt speed and an operation of electronic scales; a reduction of costs for an installation of one conveyor instead of two as it was in the former project and a location of the electrical power switching station and frequency converters on the surface of the colliery; a remote control and visualization of belt conveyor contributed to reduction the level of employment and to increase of labour safety.

## 5. GENERAL REMARKS AND CONCLUSIONS

As it has been shown in the paper many mine belt conveyors can be ranked as energy-saving. Belts both with multi-ply cord as well as with steel cord made by FTT Wolbrom, J.S.C. make a big contribution. Since these belts have the running covers made of the material based on chloroprene cautchouc (CR) characterized by a small resistance to rolling friction at denting in the temperature which occurs in the majority of underground workings in collieries. An increased belt tension in medium-length belt conveyors contributes to that, limiting in a decisive way the belt sag among the sets of rollers, which is smaller than 1%. Increased energy-saving features are obtained due to a usage of motors controlled by frequency converters – it has been shown through a comparison of the belt conveyor from the Piast Colliery with the belt conveyor from the Jankowice Colliery. An increased life of the belt and other conveyor components, resulting from soft-starts, soft-braking, a change of the belt speed, in particular an obtained arithmetical load distribution on the individual drives in the place of distribution according to Euler law, play a decisive role in this case.

In traditional design constructions of belt conveyors an incomplete use of transverse intersection nominal surface of the material handled on the belt, relatively small, internal friction of the coal run-of-mine and also an inclination of the side rollers of 30° or 35° have a certain impact on energy-saving. A variable stream of the material handled supplied onto the belt and incorrect construction of the run-of-mine dumping stations from one conveyor to the other and also an excessive use of the centring deflection of side rollers in the sets of load-bearing and return rollers have a disadvantageous impact on energy-saving.

It should be emphasized that a majority of factors, having an impact on an improvement of energy-saving conditions of belt conveyors, is known. At their designing and constructing stages the theories and methods of mechatronics for a comprehensive approach to the subject-matter under discussion should be taken into account.

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