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THE INVESTIGATIONS OF DRIVING SYSTEMS OF BELT CONVEYORS IN MINING

ISPITIVANJA POGONSKIH SISTEMA TRANSPORTERA SA TRAKOM U RUDNICIMA

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Abstract: *: The operational properties of the drives equipped with frequency converters or hydrodynamic couplings of a constant fill-up, used in belt conveyors, are described in the paper. The analysis of the results of the industrial investigations of belt conveyor confirmed the advantages of the tested hydrodynamic couplings with constant filling. The results of the tests and some important installations of belt conveyors, equipped with the drives of this type and implemented within the recent years, are presented.*

Key words: *belt conveyor driving systems, frequency converters, hydrodynamic cuplings.*

Apstrakt: *U ovom radu su opisana radna svojstva pogona opremljenih frekventnim pretvaračima (konvertorima) ili hidrodinamičkih spojnica sa stalnim punjenjem, koji se koriste u transporterima sa trakom. Analiza rezultata industrijskih proučavanja transportera sa trakom potvrdila su prednosti ispitanih hidrodinamičkih spojnica sa stalnim punjenjem. Ovde su predstavljeni rezultati ispitivanja i značajnija postrojenja transportera sa trakom, opremljenih pogonima ovog tipa i koji su pušteni u rad poslednih godina.*

Ključne reči: *Pogonski sistemi transportera sa trakom, frekventni pretvarači, hidrodinamičke spojnice.*

1 INTRODUCTION

Drives with induction motors, controlled with frequency converters, must be equipped with flexible couplings and gears, most often of the planetary type, to obtain a high value of the torque at a low value of rotations. In the drives of this type the advantages of asynchronous motors for the voltage of 500 and 1000 Volts (and higher) are fully used.

In the mining practice voltage and current frequency converters are used. The voltage converters are constructed with transistors and the current converters – with thyristors. The frequency converters under discussion are power

1 UVOD

Pogoni sa indukcionim motorima, kojima upravljaju frekventni pretvarači, moraju biti opremljeni fleksibilnim spojnicama i zupčanicima, najčešće planetarnog tipa, kako bi se dobile visoke vrednosti obrtnog momenta kod malog broja rotacija. U pogonima ovog tipa prednosti asinhronih motora za napon od 500 i 1000 volti (i više) u potpunosti su iskorišćene.

U rudarskoj praksi koriste se napon i frekventni pretvarači za struju. U naponske pretvarače su ugrađeni tranzistori i pretvarači za struju-sa tiristorima. Frekventni pretvarači o kojima govorimo su

electronic equipment designed for a start-up and soft rotational speed control of asynchronous motors in both directions.

1 OPERATIONAL PROPERTIES OF STATE OF THE ART BELT CONVEYORS

1.1 Belt conveyors drives equipped with frequency converters

The programmable microprocessor controller, installed in the current frequency converter, enables its operation in the systems of an automatic speed control of belt conveyors. The converter control system renders it possible to adjust the time of reaching the required start-up speed (rotations), the braking current (also at changing the direction of rotations), a limitation of overloading, type of breaking (regenerative breaking, dynamic braking or lack of braking). The basic advantages of belt conveyors with the drives equipped with frequency converters include:

- a soft start of a belt conveyor which does not cause voltage drops in the mains,
- a reduction of the belt tension during the start-up, which enables to use the belts of a lower strength,
- a flexible control of the torque and of the rotational speed of the motors, thus also of the belt speed in a function of the run-of-mine, a possibility of men-riding at a safe speed,
- a resistance to disturbances and changes of the mains parameters,
- a possibility of a flexible change of motion direction,
- a possibility of a full automation of the transportation system,
- significant savings of electric energy,
- an increase of the conveyor's life, mainly of its belt and rollers due to a two-fold smaller number of the belt circulations along the conveyor,
- a nearly ideal equalization of loads among the motors, driving one conveyor, which enables to use multi-drum drives and intermediate drives,
- a smaller release of heat and an operation at reduced noise,

snažna elektronska oprema namenjena za početnu i meku (slabu) rotacionu regulaciju brzine asingronih motora u oba pravca.

1 RADNA SVOJSTVA TRANSPORTERA SA TRAKOM NAJVIŠEG STEPENA RAZVOJA

1.1 Pogoni transportera sa trakom opremljeni frekventnim pretvaračima

Programabilni mikroprocesorski kontroler (mikroprocesor), koji je ugrađen u frekventni pretvarač, omogućava njegov rad u sistemima sa automatskom regulacijom brzine transportera sa trakom. Sistem regulacije pretvarača omogućava da se podesi vreme dostizanja tražene početne brzine (rotacija), isključenja (takođe u menjanju pravca rotacija), ograničenje preopterećenja, vrstu isključenja (regenerativno isključenje, dinamičko isključenje ili odsustvo isključenja). Osnovne prednosti transportera sa trakom koji imaju pogon opremljen frekventnim pretvaračima su sledeće:

- slabi start transportera sa trakom koji ne uzrokuje pad napona u mreži,
- smanjenje naprezanja trake za vreme pokretanja, što omogućava korišćenje traka manje snage,
- fleksibilna regulacija obrtnog momenta i rotacione brzine motora, a prema tome i brzine trake tokom rada rudnika, mogućnost prevoza ljudstva pri bezbednoj brzini,
- otpornost na smetnje i promene parametara mreže,
- mogućnost fleksibilne promene pravca kretanja
- mogućnost potpune automatizacije transportnog sistema,
- značajna ušteda električne energije,
- povećanje veka trajanja transportera, uglavnom njegove trake i njegovih valjaka, zahvaljujući dvostruko manjem broju cirkulacija trake duž transportera,
- skoro idealno ujednačenje opterećenja motora, koji pokreću jedan transporter, što omogućava korišćenje prenosa sa više bubnjeva i posrednog prenosa,
- manje izbacivanje toplote i rad u manje bučnom okruženju,

- regenerative braking with return of energy to the mains,
- an operation at a full cross-section of the trough, which enables a temporary storage of the run-of-mine on the belt and thus the conveyor plays a role of a storage tank of big volume.

- regenerativno isključenje sa povraćajem energije u mrežu,
- rad na punom preseku udubljenja, što omogućava privremenog skladištenja rude na traci pri čemu transporter igra ulogu rezervoar skladištenja velikog kapaciteta.

New designs of asynchronous motors, controlled with current frequency converters, are presented by the Breuer Motoren Company. These motors of the power 250, 400 and 1000 kW for the voltage of 1000 Volts, are integrated with the block of the current frequency converter and with the electronic system. These units are installed in the explosion–proof casing with a flame-proof screen and can be used in underground, gasous mines, in the workings of the explosion hazard "a", "b" and "c".

Novi nacrti za asinhrone motore, kojima upravljaju frekventni pretvarači za struju, predstavila je kompanija Breuer Motoren. Ovi motori, snage 250, 400 i 1000 kW za napon od 1000 volti, integrisani su u blok frekventnog pretvarača za struju i u elektronski sistem. Ove jedinice su instalirane u kućište otporno na eksploziju sa nezapaljivom pregradom i može se koristiti u podzemnim, metanskim rudnicima, u jamama pod opasnošću od eksplozije "a", "b" i "c".

The control system of the motor/ppc unit receives the data from the sensors installed in the unit and communicates with the master unit. Tests of these motors have proved that the maximal torque (lasting up to 30 s) should not exceed 1.5 of the rated torque, which enables to avoid a damage to the motor/ppc unit. The supply voltage exceeding 1100 Volts is transformed for the voltage of 1000 Volts in a special transformer and conducted to the current frequency converter.

Regulacioni sistem motorne/ppc jedinice dobija podatke od svih senzora koji su instalirani u jedinici i u kontaktu je sa glavnom jedinicom. Ispitivanja ovih motora su pokazala da je maksimalni obrtni momenat (koji traje do 30s) ne treba da pređe 1.5 nominalnog obrtnog momenta, što omogućava da se izbegne oštećenje motorne/ppc jedinice. Napon napajanja koji prelazi 1100 volti pretvara se u napon od 1000 volti u specijalnom transformatoru i sprovodi se to frekvetnog pretvarača za struju.

In Figure 1 the power electronic part of the current frequency converter, type PPC 2/3 is shown. The scope of speed control varies from 5 to 55 Hz and the maximal power of motors reaches 510 kW.

Na slici 1 je prikazan elektronski deo strujnog frekventnog pretvarača, tip PPC 2/3. Raspon regulacije brzine varira od 5 do 55 Hz a maksimalna snaga motora dostiže 510 kW.

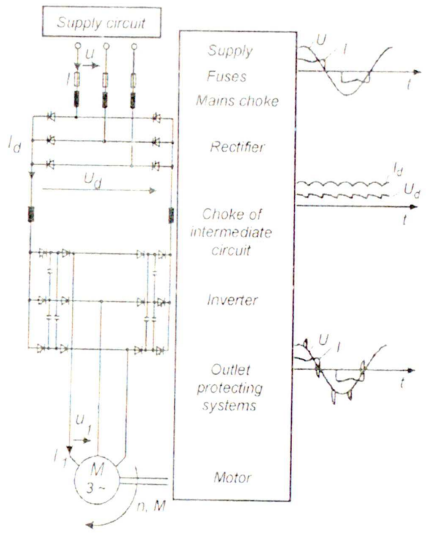

Figure 1 diagram of power electronic system of frequency converter, type PPC 2/3
slika 1 Grafikon elektro-elektronskog sistema frekventnog pretvarača, tip PPC 2/3

The mechanical characteristics of an asynchronous motor of the power 250 kW, controlled by a current frequency converter is shown in Figure 2.

Mehaničke karakteristike ansinhronog motora snage 250 kW, kojim upravlja strujni frekventni pretvarač prikazane su na slici 2.

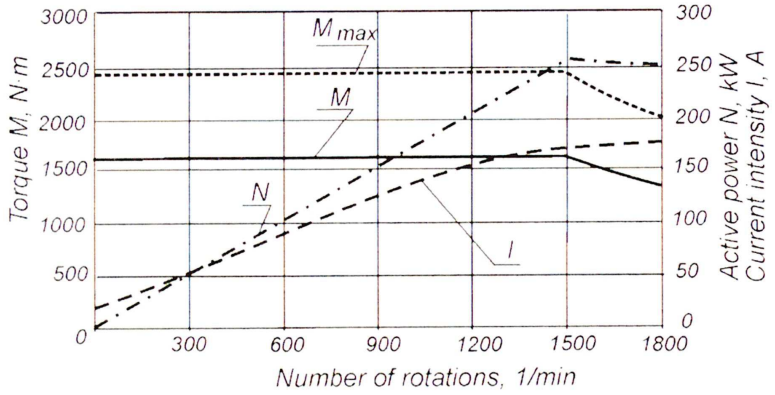

Figure 2 Mechanical characteristics of asynchronous motor, controlled with current frequency converter
slika 2 Mehaničke karakteristike asihnronog motora, kojim upravlja strujni frekventni pretvarač

A control of the rotational speed from 0 to 1500 rev/min is carried out directly at a constant rated torque M = const. An instantenous overloading of the motor during the period of 30 s, in relation to the motor construction, can vary from 150 to 170% of the rated torque or rated power. The required current intensity at a low speed is small due to a linear characteristic of the current intensity below the full speed. The heat generated in the rotor is minimal in comparison with an asynchronous motor. The number of the motor start-ups is unlimited in normal operational conditions.

Regulacija rotacione brzine od 0 do 1500 obrtaja u minutu se vrši direktno pri konstantnom nominalnom obrtnom momentu M = const. Trenutno preopterećenje motora tokom perioda od 30 s, s obzirom na konstrukciju motora, može varirati od 150 do 170% nominalnog obrtnog momenta ili nominalne snage. Potreban intenzitet struje pri maloj brzini nije veliki zbog linearnih karakteristika intenziteta struje ispod pune brzine. Toplota koja se stvara u rotoru je minimalna u poređenju sa asinhronim motorom. Broj pokretanja motora je neograničen u uobičajenim radnim uslovima.

1.2 Hydrodynamic couplings in belt conveyors

Hydrodynamic couplings with constant fill of T, TV, TVV and TVVS type and fill-controlled ones of TPKL and DTPK type produced by Voith–Turbo GmbH (Germany) are applied in drives of belt conveyors equipped with an inductive one-speed motor. Mineral oil or water are used as operating medium. Owing to their working principle (the Foettinger effect) these couplings installed in the drive chain between motor and toothed gear enable to reduce the torque transferred from motor to machine. Torque transferred by the motor is converted into the kinetic energy of operating liquid at the pump wheel, which is connected to the drive motor. At the turbine wheel the kinetic energy is converted back into the mechanical one. Hydrodynamic couplings can transfer only as much torque as their mechanical characteristics allow and that

1.2 Hidrodinamičke spojnice na transporterima

Hidrodinamičke spojnice sa stalnim punjenjem T, TV, TVV i TVVS tipa i tipa TPKL i TPK sa regulacijom punjenja, koje proizvodi Voith–Turbo GmbH (Nemačka) primenjuju se u pogonima transportera sa trakom koji su opremljeni induktivnim jednobrzinskim motorom. Mineralno ulje (sirova nafta) ili mineralna voda se koriste kao radni medijum. Zahvaljujući njihovom radnom principu (Foetingerov efekat) ove spojnice, koje su instalirane u pogonskom lancu između motora i zupčastom zupčaniku, omogućavaju smanjivanje obrtnog momenta koji se prenosi iz motora u mašinu. Obrtni moment koji prenosi motor pretvara se u kinetičku energiju pogonske tečnosti na točku pumpe, koji je povezan za pogonski motora. Na točku turbine, kinetička energija se pretvara ponovo u mehaničku. Hidrodinamičke spojnice mogu da prenesu onoliko obrtnog momenta koliko im

value is independent from the power of the motor. Motor can be put in motion very rapidly (from 1 to 2 s) despite of the belt conveyor type, so that the area of high power consumption is quickly passed and thermal ballast of the motor is very small. Hydrodynamic coupling absorbs heat produced during the belt conveyor start-up.

Thanks to their advantages over 250 hydrodynamic couplings with constant fill are applied in the Polish underground coal mines.

Couplings of the TV and TVV type with delay chambers are suitable for the belt conveyors of medium length, where the start-up torque is limited adequately to 1,6 and 1,4 of the normal demand torque. During the start-up of empty belt conveyor the transferred torque is lower than the rated torque input, which contributes to the smooth belt load, Figure 3.

dozvoljavaju njihove mehaničke karakteristike i ta vrednost je nezavisna od od snage motor. Motor se može veoma brzo staviti u pogon (od 1 do 2s) bez obzira kog je tipa transporter sa trakom, tako da se područje velike potrošnje energije brzo prelazi a termičko opterećenje motora je veoma malo. Hidrodinamična spojnica apsorbuje toplotu koja se stvara tokom pokretanja transportera sa trakom.

Zahvaljujući svojim prednostima, preko 250 hidrodinamičkih spojnica sa stalnim punjenjem se koristi u poljskim podzemnim rudnicima uglja.

Spojnice tipa TV i TVV sa komorama za zadržavanje su pogodne za transportere sa trakom srednje dužine, gde je početni obrtni moment ograničen srazmerno na 1,6 i 1,4 obrtnog momenta uobičajene potražnje (zahteva). Za vreme pokretanja praznog transportera sa trakom preneseni obrtni moment je manji nego nominalni ulaz obrtnog momenta, što doprinosi ravnomernom opterećenju trake, slika 3.

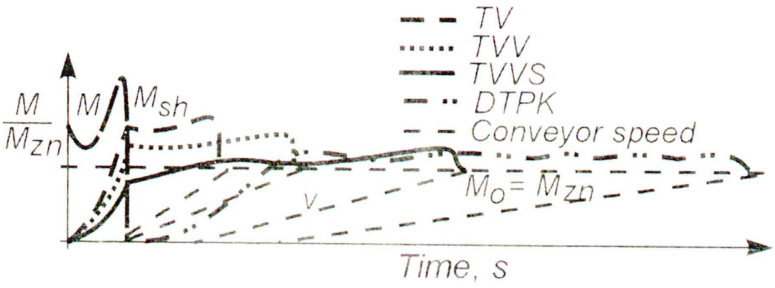

Figure 3 Changes of torques transferred by hydrodynamic couplings of various constructions as the function of start-up time; M, M_{sh}, M_o – motor torque, coupling torque and conveyor resistance torque
Slika 3 Promene obrtnih momenata prenesenih putem hidrodinamičnih spojnica različitih konstrukcija kao funkcija početnog vremena; M, M_{sh}, M_o – motorni obrtni moment, obrtni moment spojnice i obrtni moment otpora transportera

Work of hydrodynamic coupling is possible owing to slip accompanied by proportional warming up of the operating medium. Carrying off the heat takes place through the surface of coupling enclosing shell or – in case of the water flow fill-controlled hydrodynamic couplings – in the special cooling unit. The operating liquid temperature should not be higher than 60°C above the environment one.

Frequency of one-after-another start-ups and unfavourable environmental conditions, which influence carrying away of the heat from the coupling, are factors which can make application of particular type of hydrodynamic coupling difficult.

Main criteria of hydrodynamic coupling selection are rated power input and rotations of the

Rad hidrodinamičke spojnice je moguć zbog klizanja koje prati proporcionalno zagrevanje radnog medijuma. Odvođenje toplote vrši se preko površine obuhvatne školjke spojnice ili – u slučaju hidrodinamičkih spojnica sa regulacijom punjenja vodom - u specijalnim rashladnim jedinicama. Radna temperatura tečnosti ne treba da bude viša od 60°C iznad sobne temperature.

Učestalost pokretanja jednog za drugim i nepovoljni facijelni (ekološki) uslovi, koji utiču na odvođenje toplote iz spojnice, su faktori koji mogu da otežaju primenu određenog tipa hidrodinamičke spojnice.

Glavni kiriterijumi za izbor hidrodinamičke spojnice su nominalna snaga na ulazu i rotacije

squirrel-cage motor. Additional criteria are: mass moment of inertia value limiting the torque and frequency of belt conveyor start-ups.

The TVVS coupling except the enlarged delay chamber located in the motor shaft section has also an additional annular chamber (Figure 4).

elektromotora sa kratkospojenim. Dodatni kriterijumi su: moment mase inercione vrednosti koji limitira obrtni moment i učestalost pokretanja transportera sa trakama.

TVVS spojnica osim povećane komore za zadržavanje koja se nalazi u odeljku motora ima takođe prstenastu komoru (slika 4).

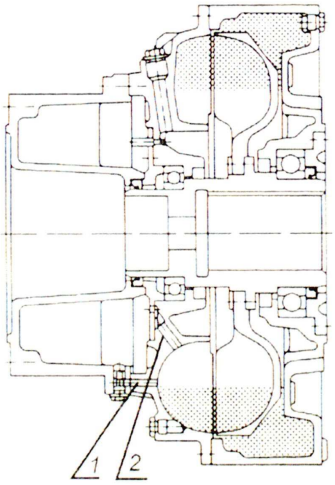

Figure 4 Constant-fill (50%) hydrodynamic coupling of TVVS type; 1 – jet, 2 – scoop pipe
slika 4 Hidrodinamička spojnica sa stalnim punjenjem (50%) tipa TVVS; 1 –slavina, 2 – mlazna cev

Coupling filled to 50% with liquid and operating with the permanent slip (2 to 3%) has been presented in this figure. This coupling comprises sizes from 422 to 866 (Fig.2). Slow increase in transferred torque is achieved by gradual outflow of the operating liquid through changeable jets (1) from the delay chamber to the operating area. The liquid is pumped back to the chamber by the scoop pipe (2). These jets make it possible to adjust individual start-up times and change of torque in a time unit to the character of belt conveyor's work. Inside each power field coupling can be adjusted to the given operational parameters by filling it (from 50 up to 80%) with the earlier calculated amount of operating oil. In the couplings of TVV and TVVS type water can also be used as operating medium. In that case these couplings are called adequately TWVV and TWVVS.

Na ovoj slici je prikazana spojnica ispunjena tečnošću do 50% i koja radi uz stalno iskliznuće (od 2 do 3%). Ova spojnica obuhvata veličine (obim) od 422 do 866 (Sl. 2). Lagano povećanje prenetog obrtnog momenta se postiže putem postepenog odlivanja radne tečnosti kroz izmenljive slavine (1) iz komore za zadržavanje do pogonske oblasti. Tečnost se pumpa nazad u komoru putem mlazne cevi (2). Ove slavine omogućavaju podešavanje vremena pokretanja i menjanje obrtnog momenta u jedinici vremena prema karakteristikama rada transportera sa trakom. Unutar svakog energetskog polja spojnica se može podesiti prema datim radnim parametrima putem punjenja spojnice (od 50 do 80%) sa prethodno izračunatom količinom pogonskog ulja. U spojnicama tipa TVV i TVVS takođe se može koristiti voda kao radni medijum. U tom slučaju ovakve spojnice se zovu TWVV odnosno TWVVS.

More and more frequently hydrodynamic couplings with reversed filling of TWVVY type filled with water and of TVVY type filled with mineral oil are applied. Operating liquid flows into the operating area during the start-up and flows out through special pipes to delay chambers and than flows back again into the

Sve češće se primenjuju hidrodinamičke spojnice sa obrnutim punjenjem, tipa TWVVY, ispunjene vodom i tipa TVVY ispunjene mineralnim uljem (naftom). Pogonska tečnost se utiče u pogonsku oblast za vreme pokretanja i ističe iz nje preko specijalnih cevi u komore za zadržavanje a zatim ponovo utiče u pogonsku oblast. Takvo kruženje

operating area. Such liquid circulation in couplings makes the start-up of belt conveyors with high mass moment of inertia smoother. To certain extend they replace the water flow fill-control-led hydrodynamic couplings.

2 SOME IMPORTANT INDUSTRIAL INSTALLATIONS OF BELT CONVEYORS WITH STATE OF THE ART DRIVES

Within the recent few years very ambitions plans of constructing belt conveyors equipped with the drives supplied with frequency converters and equipped with hydrodynamic couplings were realized. Technical characteristic of these conveyors is given in Table 1.

tečnosti u spojnicama olakšava pokretanje transportera sa trakom koji ima moment masa inercije visoke vrednosti. U određenoj meri one zamenjuju hidrodinamičke spojnice sa kontrolom protoka vode.

2 ZNAČAJNIJA INDUSTRIJSKA POSTROJENJA TRANSPORTERA SA TRAKOM NAJVIŠEG STEPENA RAZVOJA

Tokom poslednjih nekoliko godina realizovani su veoma ambiciozni planovi za izgradnju transportera sa trakom, opremljenih pogonima sa frekventnim pretvaračima i opremljenih sa hidrodinamičkim spojnicama. Tehničke karakteristike ovih transportera date su u Tabeli 1.

Table 1 Characteristics of mine belt conveyors with state-of-the-art drives
Tabela 1 Karakteristike rudarskih transportera sa trakom sa visokorazvijenim pogonima

	Name of colliery				
	Jankowice	Mysłowice	Ziemowit	Sufco (USA)	Ensdorf (Germany)
Conveyor	long, curvilinear, inclined	very long, horizontal	long, beam stage loader	very long, beam stage loader	very long, inclined
Conveyor length, m	1080	2512	1025	6096	3775
Transportation height, m	+165	~0	+10	+73	+591
Radius horizontal curvature, m/deflection angle, deg	600/5	–	–	–	–
Convex curves	3; R=200 m	–	–	–	–
Capacity, t/h	2000	1300	1200	3000	2400
Belt width, m	1.4	1.2	1.2	1.524	1.4
Belt speed, m/s	1.1÷3.15	0.1÷2.5	3.15	do 3.56	do 5.0
Drive power, kW	4x1x355	2x250	2x250 + loop 45kW	3x(2x2x300)	3x2x1000
Type of belt	GTP ST 3150	Depreux	GTP 1200/4	2000-5-fabric-plybelt 4.75 + 4.75 mm	ST 6600
Other distinguishing properties	current frequency converters of PPC 2/3 type, disc brakes, four-drum drive	disc brakes, current frequency converters of PPC 2/3 type, storage of run-of-mine ~360t	hydrodynamic couplings 562TWVVYE (Voith), disc brakes	voltage frequency converters, intermediate drives	current frequency converters, brakes, turning over of bottom belt, anti-return couplings
	sensors and state-of-the-art control				

As it can be seen from this Table four current frequency converters have been used in four single drum drives for an inclined belt conveyor of the Bogda 1400 type, installed in the Jankowice Colliery.

The drives controlled with frequency converters operate very well in belt conveyors equipped with drum, intermediate drives. A very long belt beam stage loader, installed in the Sufco Colliery in the USA (Figure 5) of the technical specification given in Table 1, is an example of such a design solution. Each of the two intermediate drives and the front drive are equipped with two driving drums and four motors of 300 kW each, supplied with 500 Volts.

Kao što se može videti iz ove Tabele, korišćena su četiri frekventna pretvarača u četiri pogona sa jednim bubnjem za nagnuti transporter sa trakom tipa Bogda 1400, koji je instaliran u ugljenokopu Jankovice.

Pogoni kojima upravljaju frekventni pretvarači rade veoma dobro u transporterima sa trakom koji su opremljeni bubnjem i sa posrednim pogonom. Utovarivač mlaza sa veoma dugom trakom, instaliran u ugljenokopu Sufko u SAD (slika 5), sa tehničkim karakteristikama datim u Tabeli 1, predstavlja primer ovakvog projektnog rešenja. Svaki od dva pogona sa posrednim prenosom i prednji pogon opremljeni su sa dva pogonska bubnja i četiri motora od 300 kW, sa napajanjem od 500 volti.

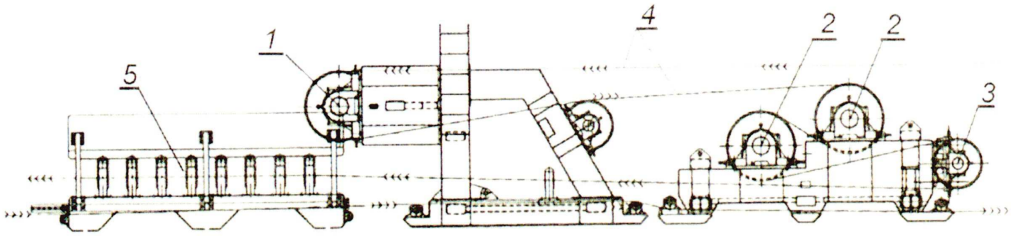

Figure 5 Double drum intermediate drive of the power 4x300 kW with the motors controlled with the voltage frequency converters; 1 – discharge drum, 2 – driving drum, 3 – drum recording the force of belt tensioning, 4 – belt, 5 – discharge area
slika 5 Posredni pogon sa dva bubnja snage 4x300 kW sa motorima kojima upravljaju naponski frekventni pretvarači; 1 – ispusni bubanj, 2 – pogonski bubanj, 3 – bubanj koji registruje silu zatezanja trake, 4 – traka, 5 – površina ispusnog otvora

Each intermediate drive (Figure 5) consists of a discharge drum, two driving drums and from the drum recording the force of the belt tensioning with the sensing system installed in the feedback loop of the belt tensioning force.

A usage of these two intermediate drives-one in the distance of 1750 metres from the discharge end and the other one in the distance of 3900 metres from the discharge end has caused a reduction of the required belt operational strength to the value of 223 N/mm lower than the required value for the fabric-plybelt of the strength 2000 N/mm. Due to that the five-plybelt EP with the covers of the thickness 4.75+4.75 mm, whose cost is lower than the cost of the steel-cord belt has been used. Simultaneously a usage of this belt has enabled to reduce the time of making connections, essential due to a need of a periodical shortening of the beam stage loader. The asynchronous motors, controlled with voltage frequency converters (made by ABB) have been used for driving the system.

Svaki prenosni pogon (slika 5) sastoji se od ispusnog bubnja, dva pogonska bubnja i bubnja koji instaliranim sistemom za monitoring kontroliše i registruje silu zatezanja trake.

Korišćenje ova dva posredna pogona-jednog na rastojanju od 1750 metara od potisne strane i drugog na rastojanju od 3900 metara od potisne strane, prouzrokovalo je smanjenje tražene radne snage trake na vrednost od 223 N/mm, što je manja vrednost od tražene vrednosti za uložak trake od prediva snage 2000 N/mm. Zbog toga je korišćen EP sa pet uložaka trake sa navlakom debljine 4.75+4.75 mm, čija je cena niža od cene trake od čeličnog užeta. Istovremeno, upotreba ove trake omogućila je smanjivanje vremena za ostvarivanje veze, uglavnom zbog potrebe za periodičnim skraćivanjem utovarivača mlaza. Asinhroni motori, kojima upravljaju naponski frekventni pretvarači (izrađene od strane ABB) korišćeni su za pokretanje sistema.

Another solution of the conveyor transportation system has been implemented in the Ensdorf Colliery (Germany) (Table 1).

In the incline on 9^0 a conveyor of the belt width 1.4 m has been installed. The transportation height of the run-of-mine is 591 metres and it is performed between the level 1000 and 400 m.

The belt conveyor is equipped with the front three-drum drive with six asynchronous motors, of 1000 kW power each, controlled with current frequency converters. A slow-burning steel-cord belt of the strength 6600 N/mm and the covers 12+10 mm has been used. The belt producer has decided that the fatigue strength of the connections in this belt will be on the level of 38%, which required an assumption of the minimal safety factor s = 5.4. Driving drums have the diameter of 1.75 metre and the belt tensioning force on the driving and discharge drum is 1710 kN. The return drum has the diameter of 1.25 metres and the deflecting one – 1.0 meter. The belt in the return branch is turned over and its initial tensioning, applied by a weight system is 120 kN. In the area of the return end a possibility of the drum displacement at the distance of 28 metres is possible.

The belt dynamic load is insignificant as it has been assumed that the maximal torque will reach only 125% of the rated torque. In the case of a failure of one motor (operational system of the drives n-1), the conveyor can continue its operation at a capacity of about 1500 t/h. The drives are equipped with anti-return couplings and with the brakes of the safety factor 1.5 in relation to the load component force of the run-of-mine on the conveyor.

3 INDUSTRIAL INVESTIGATIONS OF BELT CONVEYOR EQUIPPED WITH HYDRODYNAMIC COUPLINGS

An inclined belt conveyor (Figure 6) has been the object of investigations. The MP1 conveyor of 523,5 m length and elevating height of 86,6 m was longitudinally inclined at the angle of 9°24' and was used for the haulage of coal run-of-mine.

Jedno drugo rešenje za sistem prevoza putem transportera primenjeno je u ugljenokopu Ensdorf (Nemačka) (Tabela 1).

Pod nagibom od 9^0, instaliran je transporter sa trakom širine 1,4 metara. Transportna visina je 591 m i obavlja se na nivou između 1000 i 400 metara.

Transporter sa trakom je opremljen prednjim pogonom sa tri bubnja i šest asinhronih motora, svaki ponaosob snage od 1000 kW, kojima upravljaju sadašnji frekventni pretvarači. Korišćena je traka sa sporogorećim čeličnim užetom snage 6600 N/mm i navlakama od 12+10 mm. Proizvođač traka je odlučio da snaga izdržljivosti veza u ovoj traci bude na nivou od 38%, čime se pretpostavlja minimalni sigurnostni faktor s = 5.4. Pogonski bubnjevi imaju prečnik od 1.75 a sila zatezanja trake na pogonskom i ispusnom bubnju je 1710 kN. Povratni bubanj ima prečnik od 1.25 metara a bubanj otklona – 1.0 metar. Traka u povratnoj grani se okreće i njeno početno zatezanje, prema sistemu težine je 120 kN. U području ispusne strane, postoji mogućnost za pomeranje bubnja na razdaljinu od 28 metara.

Dinamičko opterećenje trake je neznatno pošto se pretpostavlja da će maksimalni obrtni moment dostići samo 125% nominalnog obrtnog momenta. U slučaju kvara jednog od motora (operativni sistem pogona n-1), transporter može nastaviti sa radom uz učinak od oko 1500 t/h. Pogoni su opremljeni anti-povratnim spojnicama i kočnicama sa bezbednosnim faktorom od 1,5 u vezi sa silom opterećenja komponente iskopanog materijala na transporteru.

3 INDUSTRIJSKA ISPITIVANJA TRANSPORTERA SA TRAKOM SA HIDRODINAMIČKIM SPOJNICAMA

Nagnuti transporter sa trakom (slika 6) bio je predmet ispitivanja. MP1 transporter dužine 523,5 m i visine 86,6 m nagnut je uzdužno pod uglom od 9°24' i korišćen je za transport iskopanog uglja.

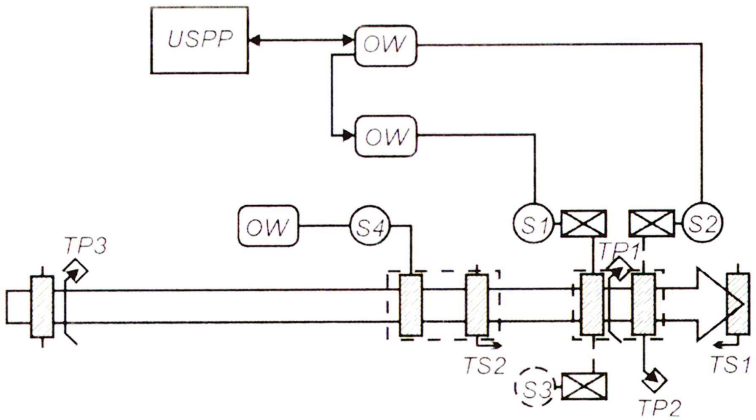

Figure 6 Schema of electric motors connections and arrangement of measuring sensors in MP1 belt conveyor at the Piast coal mine
slika 6 Šema priključaka električnih motora i raspoređivanje mernih senzora u MP1 transporteru sa trakom u rudniku uglja Piast

The belt conveyor drive consisted of two squirrel-cage asynchronous motors, 250 kW power each, installed at the first driving drum S1 and at the second one S2. The power supply voltage of the motors was 1000 V. The third motor was installed at the first drum and served as so called "hot" reserve of 250 kW power (S3). All drives were equipped with constant-fill hydrodynamic couplings of 526 TVVSC type made by Voith company and with disk breaks of ZRHT-5 type. The belt speed was 3,25 m/s. The driving drums had the diameter of 1036 mm, and idlers – 133 mm. Installed conveyor belt of 1200 mm width was of GTP 1600/4 type produced by FTT Stomil Wolbrom S.A. company. The motor of tensioning device has been marked S4.

The belt conveyor has been controlled by USPP unit through contactor switches OW. Current transformers, analogy transducers of electric quantities of SML type made by Reader u. Co company (Germany) and two-channel analogy recorders of MS-2 type have been applied to measure the active power of S1 and S2 motors. The same measurement unit has been used to investigate the intensity of current drawn by motors and to measure the voltage of motors' power supply. To investigate the belt velocity two photoelectric sensors TP1 and TP2 have been installed: the first one at the carrying idler in the area of discharge and the second one at the second driving drum. The TP3 sensor was in the tail section. Impulses from the photoelectric transducers have been intensified in the measuring amplifier and recorded by MS-2. Strain gauge sensors TS1 and TS2 have been used in order to measure the force of belt tension at the discharge drum and at the drum of tensioning

Pogon transportera sa trakom sastojao se od dva asinhrona kratkospojena elektromotora, pri čemu svaki ima snagu od 250 kW, koji su instalirani na prvom pogonskom bubnju S1 i na drugom S2. Napon napajanja motora je bio 1000 V. Treći motor je bio instaliran na prvom bubnju i služio je kao takozvana "vruća" rezerva snage 250 kW (S3). Svi pogoni su opremljeni hidrauličkim spojnicama sa stalnim punjenjem, tipa 526 TVVSC koje je proizvela kompanija Voith i sa kočnicima sa diskovima tipa ZRHT-5. Brzina trake bila je 3,25 m/s. Pogonski bubnjevi su bili prečnika 1036 mm, a remenice – 133 mm. Instalirana traka transportera, širine 1200 mm bila je tipa GTP 1600/4 koju je proizvela kompanija FTT Stomil Wolbrom S.A. Motor uređaja za zatezanje je označen S4.

Transporterom sa trakom upravlja USPP uređaj preko sklopnika OW. Električni transformatori, analogni davači električne energije SML tipa proizvedeni su u kompaniji Reader u. Co (Nemačka) a dvokanalni analogni pisači tipa MS-2 služe za merenje aktivne snage motora S1 i S2. Isti uređaj za merenje korišćen je za ispitivanje intenziteta struje koju vuku motori i za merenje napona napajanja motora. Za ispitivanje brzine instalirana su dva fotoelektrična senzora TP1 i TP2: prvi na nosećoj remenici u području ispuštanja a drugi na drugom pogonskom bubnju. Senzor TP3 je bio na zadnjem kraju. Impulsi iz fotoelektričnih davača se intenziviraju u mernom pojačivaču a registruju putem MS-2. Senzori merne trake TS1 i TS2 su korišćeni kako bi se izmerila sila zatezanja trake na ispusnom bubnu i na bubnju uređaja za zatezanje. Signali iz senzora

device. Signals from the sensors have been intensified in measuring amplifier and recorded by MS-2. The data from the measurement has been processed using professional analyzing program DIA-DAGO made by DMT Company (Germany) and PC.

se intenziviraju u mernom pojačivaču a registruju putem MS-2. Podaci dobijeni merenjem se obrađuju uz pomoć profesionalnog programa za analiziranje DIA-DAGO koji je proizvela kompanija DMT Company (Nemačka) i PC.

The oscillogram showing the start-up process of belt conveyor loaded with 22,9 t has been presented in the Figure 7.

Na slici 7 prikazan je oscilogram koji pokazuje proces pokretanja transportera sa trakom koji nosi teret od 22,9 t.

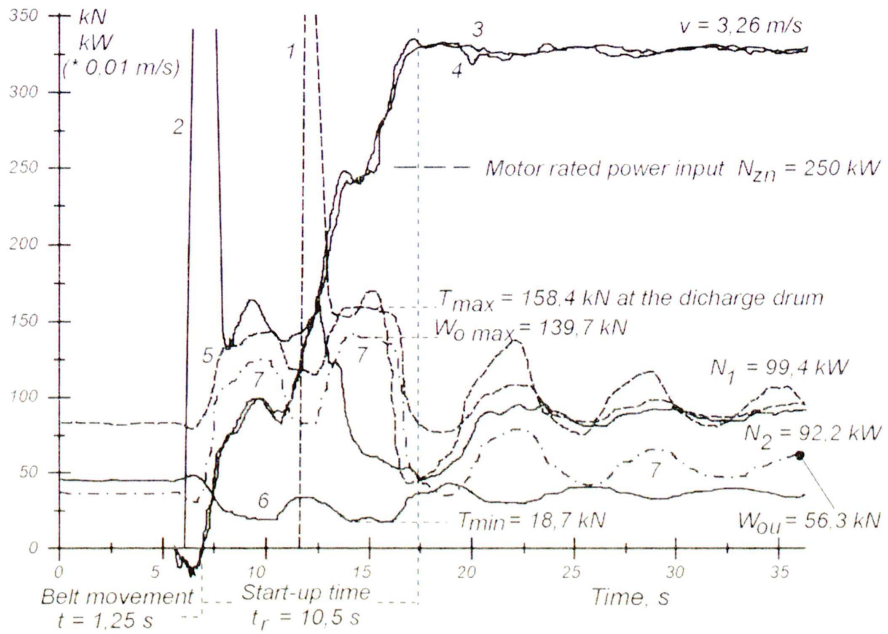

Figure 7 Oscillogram showing the start-up of loaded MP1 belt conveyor
slika 7 Oscilogram koji prikazuje pokretanje natovarenog transportera sa trakom MP1

The following quantities have been shown on this oscillogram: representations of S2 motor active power (curve 2) and S1 motor (curve 1), representations of lin-ear velocity of a drum with the S2 motor (curve 3 – value from the diagram has to be multiplied by 0,01 in order to obtain velocity in m/s), belt velocities recorded by TP1 sensor (curve 4 – value taken from the diagram has to be multiplied by 0,01 to obtain velocity in m/s), belt tension force in the area of discharge drive (curve 5), belt tension force at the drum of tensioning device (curve 6) and effective tension W_o (curve 7) as a difference of forces in belt (curve 5 and curve 6). Representations of these quantities have been measured in the function of time.

Na ovom oscilogramu su prikazane sledeće količine: prikazi aktivne snage S2 motora (kriva 2) i S1 motora (kriva 1), prikazi linearne brzine bubnja sa motorom S2 (kriva 3 – vrednost iz grafikona treba da se pomnoži sa 0,01 kako bi se dobila brzina u m/s), brzine trake koje registruje TP1 senzor (kriva 4 – vrednost iz grafikona treba da se pomnoži sa 0,01 kako bi se dobila brzina u m/s), sila zatezanja trake u području ispusnog pogona (kriva 5), sila zatezanja trake na bubnju uređaja za zatezanje (kriva 6) i efektivno naprezanje (zatezanje) W_o (kriva 7) kao razlika sila u traci (kriva 5 i kriva 6). Prikazi ovih količina su izmereni u funkciji vremena.

Results of measurements have shown that the average velocity of a stress wave spreading in belt is from 760 to 790 m/s. Total coefficient of main resistances and algebraic sum of concentrated resistances C·f = 0,0295 (see DIN 22101).

Rezultati merenja su pokazali da je prosečna brzina širenja talasa naprezanja u traci od 760 do 790 m/s. Ukupni koeficijent glavnog otpora i algebarski zbir koncentrisanih otpora C·f = 0,0295 (videti DIN 22101).

The analysis of oscillograms shows, that start-up acceleration amounted to 0,45 m/s^2 for the empty inclined belt conveyor and to about 0,31 m/s^2 for the loaded one. During the start-up the ratio of maximal force in the belt to the force in the belt in steady motion was about 2,47 for the empty belt conveyor and only 1,72 for the loaded one. Torque limitation during start-up of loaded belt conveyor amounts to 1,5 of the normal demand torque. The automatic load sharing on both drives and virtually unloaded start and run-up of motors have been observed. The transmitted driving torque increased only after the motors have reached their nominal rotational speed.

The turbo coupling behaves according to the propeller law. The torque transmitted increases with the square and the power transmitted with the cube of the input speed. The starting conditions of the coupling allow the electric motor to start-up under virtually no load because the load characteristic at start-up is parabolic.

No wear occurs; no mechanical contact of the power transmitting parts occurs.

The motor is only loaded with the full coupling torque after reaching its pullout speed. After run-up of the machine, the motor is just loaded with the required torque of the driven machine at low coupling slip. The lost of power is proportional to the slip.

The analysis of the results of the industrial investigations of belt conveyor confirmed the advantages of the tested hydrodynamic couplings with constant filling.

4 CONCLUSIONS

Based on the practical and experimental study reported on here, it can be concluded that:

- drives with induction motors, controlled with frequency converters,
- drives with hydrodynamic couplings with constant fill and fill – controlled applied in heavy – duty mine belt conveyors indicate advantageous properties especially with soft start-up and a reduction of dynamic load. The advantages of these drives have been presented in the paper.

Analiza oscilograma pokazuje da je ubrzanje kod pokretanja iznosilo 0,45 m/s^2 za prazan nagnuti transporter a oko 0,31 m/s^2 za natovaren. Za vreme puštanja u rad transportera koeficijent maksimalne snage u traci prema snazi u traci u ravnomernom kretanju bio je oko 2,47 kod praznog transportera a samo 1,72 kod punog. Ograničenje obrtnog momenta tokom puštanja u rad punog transportera sa trakom iznosi 1,5 uobičajenog angažovanog obrtnog momenta. Uočena je automatska podela tereta na oba pogona i praktično neopterećen start i pokretanje motora. Prenet pogonski obrtni moment se povećao tek pošto su motori dostigli svoju nominalnu rotacionu brzinu.

Turbo spojnica se ponaša u skladu sa zakonom elise. Obrtni moment koji je prenet, povećava se na kvadrat a preneta snaga na kub ulazne brzine. Početno stanje spojnice omogućava da se elektromotor pokrene pod praktično nikakvim opterećenjem jer su karakteristike opterećenja kod pokretanja paraboličkі.

Nema habanja; nema mehaničkog kontakta delova koji prenose energiju.

Motor je opterećen punim obrtnim momentom spojnice tek pošto dostigne svoju vučnu brzinu. Nakon puštanja mašine u rad, motor je opterećen samo potrebnim obrtnim momentom vođene mašine pri maloj vrednosti klizanja spojnice. Gubitak snage je proporcionalan klizanju.

Analiza rezultata industrijskih ispitivanja transportera sa trakom potvrdila je prednosti testiranih hidrodinamičkih spojnica sa stalnim punjenjem.

4 ZAKLJUČAK

Na osnovu praktične i eksperimentalne studije koja je ovde predstavljena, može se zaključiti da:

- pogoni sa indukcionim motorima, kojima upravljaju frekventni pretvarači,
- pogoni sa hidrodinamičkim spojnicama sa stalnim punjenjem i kontrolisanim punjenjem primenjeni u rudarskim transporterima sa trakom namenjene za teške uslove rada, pokazuju povoljna svojstva naročito u laganom pokretanju i pri smanjenjenju dinamičkog opterećenja. U ovom radu su predstavljene prednosti ovih pogona.

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