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THE APPLICATION OF FREQUENCY CONVERTERS FOR THE REGULATION OF BELT CONVEYOR DRIVES IN SURFACE MINING

PRIMENA FREKVENTNE REGULACIJE POGONA TRANSPORTERA SA GUMENOM TRAKOM NA POVRŠINSKIM KOPOVIMA

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Abstract: *Over the last few years in countries with developed mining industry belt conveyors are being equipped with variable speed drives, based on frequency converters and standard squirrel-case motors and reduction gears. Compared with regular motors that have constant voltage and frequency these drives are able to cut down energy consumption and reduce wear and tear of belt and mechanical fittings. Adequate operating and control routines and up-to-date diagnostics equipment enable designs and implementation of efficient conveyor systems with minor operating costs and high availability. This approach will be applied for the fist time in our country at the open pit mine Tamnava – West Filed for overburden haulage.*
This paper describes the frequency converter routine for the regulation of belt conveyor drives pointing out the results achieved at surface mines.

Key words: belt conveyors, *frequency converter routine*

Apstrakt: *Poslednjih godina u rudarski razvijenim zemljama sve veći broj transportera sa gumenom trakom je opremljen pogonima sa promenljivim brzinama, zasnovanim na frekventnim pretvaračima, uz korišćenje standardizovanih kaveznih motora sa reduktorima. U poređenju sa standardnim motorima sa konstantnim naponom i konstantnom frekvencijom, ovi pogoni omogućavaju značajno smanjenje potrošnje energije i habanja mehaničkih delova i trake. Primenom adekvatnih sistema za kontrolu i upravljanje, kao i savremene opreme za dijagnostiku, moguće je projektovati i izvesti efikasne transportere sa malim eksploatacionim troškovima i visokom raspoloživošću. Ovaj koncept pogona prvi put će biti primenjen u našoj zemlji na površinskom kopu «Tamnava-Zapadno polje» na sistemu za transport otkrivke.*
U ovom radu dat je prikaz koncepcije frekventno regulisanih pogona i efekti primene ovih sistema na transporterima sa gumenom trakom na površinskim kopovima.

ključne reči: *tranasporteri sa gumenom trakom, frekventno regulisani pogoni*

1 INTRODUCTION

Large lignite reserves in Serbia and favourable circumstances, such as the location of mining districts regarding transmission of energy and distribution to large consumers, mining, geological

1 UVOD

Velike rezerve lignita u Srbiji i povoljne lokacije basena sa aspekta prenosa energije i snage do velikih potrošača, rudarsko-geološki i klimatski uslovi, geometrije ležišta i fizičko-mehaničke and climatic conditions, deposit geometry, physical and mechanical properties of working environment provide good prospects for opening large surface mines with the implementation of continuous systems. Almost every open pit mine within the mining districts of Kosovo, Kolubara and Kostolac has introduced high-capacity continuous operating equipment for overburden removal and coal mining. Stripping, conveyance and disposal of overburden is performed by means of the so-called ECS systems comprising bucket-wheel or bucket-chain excavator, belt conveyor and stacker. Coal mining is carried out by means of ECL that consists of bucket-wheel or bucket-chain excavator, belt conveyor and loader or ECC that includes bucket-wheel or bucket-chain excavator, belt conveyor and crushing plant.

It is therefore obvious that belt conveyors represent an essential element of these systems. Presently, the most commonly used conveyors have belts that are 3200-mm wide, capacity per each driving station up to 12000kW, conveying speed of 7.5 m/s and an output of up to 40.000 m^3/h. It should be noted that recently, belt conveyors are becoming longer, which implies the installation of intermediate drives. In such circumstances the development of curvilinear belt conveyors in horizontal planes proved to be particularly convenient enabling conveyor lengths of 10 or more kilometres. The 100-km conveyor line is the longest installed and it comprises 10 separate conveyors. Over the last few years particular attention has been paid to the development of flexopipe conveyors and conveyors able to negotiate highly slanted terrains. The most widely used conveyors in our country are from 1.200 to 2.000 mm wide, their speed range from 3.5 to 5.4 m/s, and their output reaches 8.000 m^3/h. The belts are of plies made either of PVC fibres (67%) or of steel cords (33%). Overall conveyor length at surface lignite mines in Serbia is 117.500 meters, of which 43.500 meters are installed in Kolubara mining district, 47.000 meters in Kosovo mining district and 27.000 meters in Kostolac mining district.

Conventional conveyance facilities are still prevailing in open pit lignite mines. In fact, there seems to be no development in this area, however, it should be emphasised that over the last two decades driving and controlling units have been considerably improved. Besides, extensive investigations have been carried out to determine the processes that occur at the moment of conveyor startups and halts. Essential requirements expected from new designs are improved reliability, higher unit output, minimum size and weight of driving units, reduced maintenance costs, improved safety for operators, reduced power costs etc.

Certainly, the most significant improvement is achieved by introducing frequency converters for the regulation of high power and high voltage

karakteristike radne sredine, pružli su mogućnost za otvaranje velikih površinskih kopova i za uvođenje u eksploataciju tehnoloških kompleksa kontinuiranog dejstva. Na skoro svim površinskim kopovima u okviru Kosovskog, Kolubarskog i Kostolačkog basena na otkopavanju otkrivke i uglja u primeni je visokoproduktivna mehanizacija kontinuiranog dejstva. Na otkopavanju, transportu i odlaganju otkrivke koriste se BTO sistemi (rotorni bageri ili vedričari – transporteri sa gumenom trakom – konzolni odlagači), a na eksploataciji uglja BTD ili BTU sistemi (rotorni bageri ili vedričari – transporteri sa gumenom trakom – utovarna mesta ili drobilična postrojenja).

Dakle, jedan od osnovnih elemenata u sistemu su transporteri sa gumenom trakom. Danas se u svetu primenjuju transporteri širine do 3200 mm, instalisane snage po pogonskoj stanici do 12000 kW, sa brzinom transporta do 7.5 m/s kapaciteta do 40.000 m^3/h. Kod transportera sa gumenom trakom, poslednjih godina, izražen je trend razvoja veoma dugačkih transportera sa međupogonima. Posebna pogodnost je razvijanje konstrukcija sa krivinama u horizontalnoj ravni, tako da dužine transportera dostižu 10 i više kilometara. Najduže ugrađena transportna linija je dužine 100 km izvedena sa 10 individualnih transportera. Intezivno se razvijaju i cevasti (flexopipe) i transporteri za transport pod velikim nagibom. U našoj zemlji u primeni su transporteri čije se širina kreće od 1.200 do 2.000 mm, brzine od 3.5 do 5,4 m/s a kapaciteti do 8.000 m^3/h. Primenjuju se gumene trake sa ulošcima od sintetičkih vlakana (67%) i ulošcima od čeličnih užadi (33%). Ukupna dužina transportera na površinskim kopovima lignita u Srbiji je 117.500 metara, pri čemu je u Kolubarskom basenu instalisano 43.500 metara, u Kosovskom basenu 47.000 metara i u Kostolačkom basenu 27.000 metara.

Na površinskim kopvima lignita još uvek su dominantna klasična transportna postrojenja. Na prvi pogled se ne uočava neka razvojna tendencija, ali se mora naglasiti da u poslednje dve decenije pogonski i upravljački delovi transportera su zantno unapređeni. Takođe, intenzivna su proučavanja prelaznih procesa koji se javljaju kod pokretanja i zaustavljanja transportera. Osnovni zahtevi koji se postavljaju pred nove konstrukcije su povećanje pouzdanosti, povećanje jediničnih kapaciteta, minimiziranje veličine pogona i težine, smanjenje cene održavanja, povećanje sigurnosti rukovaoca, smanjenje troškova energije i dr.

Svakako da je najvažniji napredak ostvaren sa frekventnom regulacijom pogonskih motora velike snage i visokog napona, odnosno transportera driving motors for high capacity conveyors. SIMENS has supplied an electric unit with frequency regulation for conveyors of following features: output 7500 t/h, conveyor length 2530 m, belt width 2000 mm, belt St-3150, belt speed ranging from 3,3 to 6,55 m/s, power of electric motor 2470 kW (at maximum rpm). Wide-ranging regulation of revolutions per minute and torque of electric motor provides an smooth start, thus reducing belt tension considerably if compared with the conventional drives equipped with hydrodynamic clutches or slide rings. Electrical braking reduces the number of revolutions to minimum.

The regulation of belt speed provides optimised loading of belt and therefore savings in energy consumption up to 20%. Apart from these immediate effects, certain indirect advantages may also be pointed out, such as easy maintenance considering that the motors are not equipped with brushes, longer service life of gear wheels etc.

2 BASIC DESIGN FEATURES OF FREQUENCY CONVERTERS

Basic design features of frequency converters should explain the way in which this device operates and to emphasise the advantages of its application in electric motor drives. Figure 1 presents a simplified diagram of frequency converter.

velikih kapaciteta. SIMENS je isporučio elektropostrojenje sa frekventnom regulacijom za transporter sledećih karakteristika: kapacitet 7500 t/h, dužina transportera 2530 m, širina trake 2000 mm, traka St-3150, brzina trake 3,3 do 6,55 m/s, snaga elektromotora 2470 kW (pri max. broju obrtaja). Široka oblast regulacije broja obrtaja i obrtnog momenta elektromotora omogućava veoma meki start tako da se zatezna sila u traci menja daleko manje nego kod klasičnih pogona sa hidrodinamičkom spojnicom ili sa kliznim prstenovima. Kočenje se vrši takođe električnim putem do minimalnog broja obrtaja.

Podešavanjem brzine trakeomogućava se optimalna količina materijala na traci i ušteda u potrošnji energijei do 20%. Pored direktnih efekata prisutne su i posredne prednosti u procesu održavanja: nema četkica na motorima, duži radni vek zupčanika i sl.

2 OSNOVNE KARAKTERISTIKE (KONSTRUKCIJA) FREKVENTNIH PRETVARAČA

Kratak opis konstrukcije frekventnog pretvarača treba da objasni način rada uređaja, i ukaže na prednosti njegove primene u elektromotornim pogonima. Uprošćena šema pretvarača data je na slici 1.

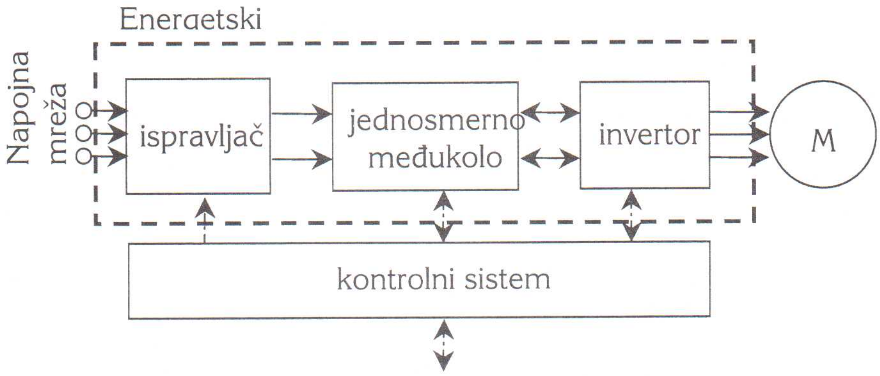

Figure 1 Simplified diagram of frequency converter
slika 1 Uprošćena šema frekventnog pretvarača

Power unit - The power unit of this device consists of rectifier, direct intermediate circuit and inverter. The rectifiers in converters may be uncontrollable or controllable. Uncontrollable rectifiers or diode rectifiers are simple and reliable, where the alternating power supply voltage and the first multiple of current fundamental frequency are

Energetski deo - Energetski deo uređaja čine ispravljač, jednosmerno međukolo i invertor. Ispravljači u pretvaračima mogu biti neupravljivi, ili upravljivi. Neupravljivi ispravljači ili diodni ispravljači su jednostavni i pouzdani, i kod njih su naizmenični napon napajanja i prvi harmonik struje praktično u fazi. Ovo značajno doprinosi da je ukupan faktor practically in the same phase. This considerably improves to the total power factor of the converter if compared with asynchronous motors that are supplied directly from the power line. Controllable rectifiers are thyristor or recently transistor devices. Controllable rectifiers are power-recuperative, i.e. they are able to provide two-way power transmission, from the power line towards the driving unit and from the driving unit back to the power line. This is particularly important for drives with considerable potential or kinetic energy, which tends to be released under specific circumstances and turned back to the distribution network, which provides substantial savings. Nowadays, thyristor rectifiers are available on the market and in comparison with the transistor rectifiers they are more suitable for high-power and high-voltage units. However, thyristor rectifiers may have some disadvantages with respect to network features, such as inferior power factor and multiple harmonics in the current. Transistor rectifiers or active front end provide tow-way transmission of energy with unit power factor and a rather low content of higher harmonics in network current. In addition to this active front ends are able to maintain constant voltage in direct circuit even up to 65% of main voltage and may be used as active compensators of reactive power at the supply busbars. However, it should be kept in mind that usually low-voltage active front ends, up to 690V presently available on the market and only a few larger manufacturers offer active front ends for medium voltage. With respect to the price diode rectifiers are considered as the most favourable solution, followed by thyristor and finally transistor rectifiers or active front ends, which are the most expensive ones.

Direct intermediate circuit consists of LC filter, which has the function to filter direct voltage entering the inverter. However, the inductance of this circuit conduces to damping of higher harmonicas at the network side. This should be taken into account when adequate converters are to be selected. The dampers (of the reactor) should be certainly included or converters from regular supplier. If the driving unit requires electric braking it is an option to install into a braking system the direct circuit. This system consists of braking module (one transistor unit) and one resistor to dissipate the braking energy. The previously described braking system is not necessary if some of the formerly mentioned controllable rectifiers.

The inverter includes six sets of fully controllable semiconductor breakers (power transistor) in three-phase bridge connection. The latest generations of converters operate with the breakers in pulse duration modulation regime (PWM) at high breaker frequencies of several kHz. Owing to this the current practically forms a sine curve as shown in Figure 2. This last feature represents a significant

snage pretvarača veći, bolji nego kod asinhronih motora koji se direktno napaju iz mreže. Upravljivi ispravljači su tiristorski, ili u novije vreme tranzistorski. Upravljivi ispravljači omogućavaju rekuperaciju energije, tj. prenos energije u oba smera, od mreže prema pogonu, i od pogona nazad u mrežu. Ovo je od posebnog značaja u pogonima gde postoji značajna količina potencijalne ili kinetičke energije koja se pod određenim uslovima oslobađa, i njenim vraćanjem u distributivnu mrežu se mogu ostvariti značajne uštede. Tiristorski ispravljači danas raspoloživi na tržištu, mogu biti za veće snage i više napone u odnosu na tranzistorske. Međutim, tiristorski ispravljači imaju nepovoljnije karakteristike u pogledu odnosa prema mreži, loš faktor snage, i prisutnost viših harmonika u struji. Tranzistorski, ili aktivni ispravljači (Active Front End) omogućavaju dvosmerni prenos energije, sa jediničnim faktorom snage i vrlo niskim sadržajem viših harmonika u struji mreže. Takođe, aktivni ispravljači omogućavaju održanje stalnog napona u jednosmernom kolu sve do 65% napona mreže, i mogu se koristiti kao aktivni kompenzatori reaktivne snage na sabirnicama sa kojih se napajaju. Međutim, treba imati u vidu da se danas na tržištu najčešće nude aktivni ispravljači za niske napone, do 690V, dok samo nekoliko najvećih proizvođača raspolaže rešenjima za srednji napon napajanja. U pogledu cene najpovoljniji su diodni ispravljači, zatim tiristorski i na kraju tranzistorski, aktivni ispravljači.

Jednosmerno među kolo čini LC filter čija je osnovna uloga filtriranje jednosmernog napona na ulazu u invertor. Međutim, induktivnost ovog kola doprinosi prigušenju viših harmonika na strani mreže. Kod izbora pretvarača to treba imati u vidu, i obavezno uključiti ove prigušnice (reaktora) u specifikaciju, ili uzeti pretvarač od proizvođača koji ih standardno ugrađuje. Kod pogona gde postoji potreba za primenom električnog kočenja u jednosmerno kolo se opciono ugrađuje sistem za kočenje, koji čini moduo za kočenje (jedan tranzistor snage) i jedan otpornik za disipaciju energije kočenja. Opisani sistem za kočenje nije potreban ako se koristi neki od pomenutih upravljivih ispravljača.

Invertor čini šest grupa punoupravljivih poluprovodničkih prekidača (tranzistora snage) u trofaznoj mostnoj sprezi. Kod pretvarača današnjih generacija prekidači rade u režimu impulsno širinske modulacije (PWM), na visokim prekidačkim učestanostima, od nekoliko kHz. Zahvaljujući tome struja motora ima praktično sinusan oblik, kao što je prikazano na slici 2. Ova poslednja činjenica je značajan benefit pogona sa frekventnim advantage of diving units with frequency converters, since no additional loss occurs in the motor as in case of network power supply, which means that it is possible to use standard asynchronous motors, or already available motors in case of driving unit rehabilitation.

pretvaračima, jer u motoru ne nastaju nikakvi dodatni gubici, u odnosu na rad pri napajanju iz mreže, što znači da se mogu koristiti standardni asinhroni motori, odnosno kod rekonstrukcije pogona već postojeći motori.

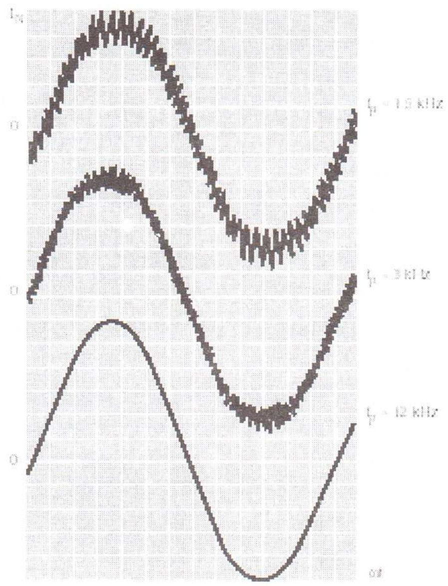

Figure 2 Motor current at different inverter breaker frequencies

slika2 Izgled struje motora pri različitim prekidačkim učestanostima invertora

Converter power unit design proves to be highly effective and its efficiency rate ranges from 0,95 to 0,99.

From the point of view of this paper it is necessary to mention the converter configuration characteristic for multi-motor drives used in belt conveyors. In such cases the configuration with common direct circuit is used for every driving unit, which power all inverters. The direct circuit is powered from the network via two rectifiers, one diode and one controllable, presently transistor rectifiers are used in most cases. The total power of both rectifiers is equal to the sum of powers from all driving units. The ratio of powers depends on the available energy that may be returned to the network and according to it is possible to size the controllable rectifier. This method provides optimum ratio between price and performance.

Control system - The control system is based on a microprocessor and makes proficient safety and regulation system. Its integration into converter the device becomes auto-protective with numerous highly efficient protections. It is also possible to achieve different ways of control and regulation, primarily regarding speed. The processor enables communication with the unit, between separate drives, if there are several, and with the superior control level.

Konstrukcija energetskog dela pretvarača obezbeđuje visoku energetsku efikasnost, tako da mu je stepen iskorišćenja između 0,95 i 0,99.

Sa aspekta ovog rada treba pomenuti konfiguracije pretvarača karakteristične za višemotorne pogone, kakvi su pogoni kod tračnih transportera. U ovakvim slučajevima se primenjuje struktura sa zajedničkim jednosmernim kolom za sve pogone, iz koga se napajaju svi invertori. Jednosmerno kolo se iz mreže napaja preko dva ispravljača, jednog diodnog i jednog upravljivog, danas najčešće tranzistorskog. Ukupna snaga oba ispravljača je jednaka zbiru snaga svih pogona. Odnos snaga ispravljača zavisi od raspoložive energije koja se može vratiti u mrežu, naime prema njoj se dimenzioniše upravljivi ispravljač. Na ovaj način se postiže optimalan odnos cene i performansi.

Kontrolni sistem - Kontrolni sistem baziran je na mikro-procesoru i čini jedan moćan zaštitni i regulacioni sistem. Njegovom integracijom u pretvarač uređaj postaje autoprotektivan, sa brojnim zaštitama vrlo visoke efikasnosti. Takođe, moguće je realizovati različite načine upravljanja i regulacije, pre svega po brzini. Procesor omogućava i komunikaciju sa postrojenjem, između pojedinih pogona, ako ih ima više, i sa nadređenim nivoom upravljanja.

Protective function - Depending on protection types the control system either activates the alarm or switches off the driving unit by simply blocking the transistor in the inverter. Every warning and alarm is memorised in the processor thus providing clear insight into the faults or errors that occurred during operation. The protective functions are:

- Protection against overheating of converters and motors. The temperature is measured in its cooling device on which semiconductor converters are fitted. In case of overheating the alarm is set and the driving unit is stopped. In the same way it is possible to protect the motor if it is equipped with a thermistor, which is connected to the converter. If motors are without thermistors the processor calculates the approximate motor temperature on the basis of motor load. This information activates the alarm or after a previously set time switches off the drive.
- Protection against over-current is instantaneous protection
- Protection against load asymmetry. Based on continuous measurements of currents in all three phases the asymmetry of currents is detected, i.e. faults in the motor or in the supply leads.
- Protection against ground connection. Ground connection in supply leads or in motor is manifested as extreme case of asymmetry and may be detected as such.
- Under-voltage and over-voltage protection. Measurement of voltage in direct intermediate circuit enables detection of over-voltage and under-voltage both in power-line and motor voltage.
- Phase asymmetry. Phase asymmetry during power supply is also detected applying voltage measurements of direct intermediate circuit.

From the previous it is obvious that the converter has a high-performance integrated protective system and therefore it is not necessary to apply any of the standard protective devices, or an automatic switch. This provides reduced costs, space, distribution and the number of elements, which improves overall reliability.

Control and regulation functions

- Speed adjustment - One of the essential features of frequency converters is to provide continuous speed adjustment of the standard squirrel-cage asynchronous motor applying supply voltage frequency.

Zaštitne funkcije - U zavisnosti od vrste zaštite kontrolni sistem reaguje upozorenjem ili isključenjem pogona, jednostavnim blokiranjem tranzistora u invertoru. Sva upozorenja i reagovanja zaštite procesor memoriše, tako da se naknadno može videti kada i koja greška se dogodila. Zaštitne funkcije su:

- Zaštita od pregrevanja, i pretvarača i motora. U pretvaraču se meri temperatura njegovog hladnjaka na kome su poluprovodnički pretvarači, u slučaju pregrevanja dobija se upozorenje, a zatim se pogon zaustavlja. Na isti način može da se štiti i motor ako ima termistor, koji se povezuje na pretvarač. Kod motora bez termistora procesor na osnovu opterećenja motora izračunava približnu temperaturu motora i na osnovu toga se aktivira upozorenje, odnosno posle podešenog vremena i isključuje pogon.
- Zaštita od preko-struje je trenutna zaštita.
- Zaštita od nesimetrije opterećenja. Na osnovu stalnog merenja, struja u sve tri faze motora detektuje se nesimetrija struja u motoru, odnosno greška u motoru, ili napojnom vodu.
- Zaštita od zemljospoja. Zemljospoj u napojnom vodu ili u motoru manifestuje sa kao ekstremni slučaj nesimetrije pa se tako može i detektovati.
- Podnaponska i prenaponska zaštita. Merenje napona u jednosmernom među-kolu omogućava detekciju prenapona i podnapona, i na strani napajanja i na strani motora.
- Nesimetrija faza. Nesimetrija faza u napajanju se takođe detektuje na osnovu merenja napona jednosmernog među-kola.

Na osnovu izloženog očigledno je da pretvarač ima integrisan zaštitni sistem vrlo visokih performansi, tako da pri ugradnji pretvarača ne treba koristiti ni jednu od standardnih motornih zaštita, niti automatski prekidač. Na ovaj način štede se značajna investiciona sredstva, prostor u razvodu, i smanjuje se broj elemenata u postrojenju, a time se ukupna pouzdanost povećava.

Upravljačke i regulacione funkcije su:

- Podešavanje brzine. Osnovna karakteristika pretvarača učestanosti je mogućnost kontinualnog podešavanja brzine standardnog kaveznog asinhronog motora promenom učestanosti napona napajanja.
- Regulacija brzine. Za razliku rada u otvorenoj sprezi kod podešavanja brzine, moguće je

Speed regulation - Unlike the open coupling the speed can be adjusted by means of regulation in closed coupling with speed pickups, tacho-generators or encoders. This regulation method provides accuracy in maintaining constant speed, which is over 0,1%. For less demanding drives, as for conveyor belts an accuracy of 0,5% is acceptable and speed regulation is possible without pickups. The operation without speed pickups is more reliable, which is very important for heavy-duty driving units. If the mechanical fittings (clutches, reduction gear, motor) of a driving unit risk damage due to impact load it is possible to achieve the so-called "smooth" feature of the motor by adjusting speed regulation parameters. This makes the driving unit capable of absorbing and withstanding impact loads at any time.

- Acceleration/deceleration control - Start/stop or speed modification is carried out in line with previously specified speed accretion in time, which means that these processes are adjusted to drive requirements and possibilities.
- Process control - All system values that are causally dependant on speed of the motor powered by the converter may be controlled by it or regulated if adequate information on process condition is provided, for example conveyor belt loading condition.

Previously stated features enable considerable simplification of drive transmission system. Speed adjustment and regulation capabilities exclude the use of multistage reduction gears or mechanical variable speed regulators. The adjustment of acceleration or deceleration, as a mean to absorb "smoothly" impact loads includes the use of elastic or hydrodynamic clutches.

Converter communication - Converter communication options offer large possibilities for command and control at the site, from immediate vicinity or at long distance. Communication options include:

- Local communication is used for adjustment, command and control over converter operation, or over the entire driving unit at the site, that is at the very converter. This command unit consists of a display and a keyboard.
- Digital inputs and outputs - Brand name converters have several digital inputs and outputs, usually at 24VDC, which allows the interchange of logical commands with the environment

- koristiti regulaciju brzine u zatvorenoj sprezi, sa davačem brzine, tahogeneratorom ili enkoderom. Kod primene ovakve regulacije postiže se tačnost održavanja brzine veća od 0,1%. Kod manje zahtevnih pogona, kao što su transportne trake, moguća je regulacija brzine bez davača sa tačnošću od 0,5%. Rad bez davača brzine je mnogo pouzdaniji, što je vrlo bitno kod pogona u teškim uslovima rada. Kod pogona gde postoji opasnost od oštećenja mehaničkih sklopova (spojnica, reduktora, motora) usled udarnog opterećenja moguće je podešavanjem parametra regulatora brzine postići «meku» karakteristiku motora, tako da pogon lako prima i podnosi udarna opterećenja.
- Kontrola ubrzanja i usporenja. Polazak, zaustavljanje, ili promena brzine pogona odvijaju se sa unapred zadatim priraštajem brzine u vremenu, tako da se ovi procesi prilagođavaju potrebama i mogućnostima pogona.
- Kontrola procesa. Sve veličine u sistemu koje su posledično zavisne od brzine motora koji se napaja iz pretvarača mogu se preko pretvarača kontrolisati, ili regulisati ako se obezbedi odgovarajuća informacija o stanju procesa, npr. napunjenost trake transportera.

Zahvaljujući navedenim karakteristikama transmisioni deo pogona se može značajno uprostiti. Mogućnost podešavanja ili regulacije brzine isključuje potrebu za korišćenjem višestepenih reduktora ili mehaničkih varijatora brzine. Podešavanje ubrzanja ili usporenja, kao mogućnost «mekog» prihvatanja udarnih opterećenja isključuje potrebu za korišćenjem elastičnih ili hidrodinamičkih spojnica.

Komunikacija pretvarača - Komunikacione opcije pretvarača pružaju velike mogućnosti u pogledu komandovanja i nadzora nad pretvaračem, kako sa lica mesta, ili iz neposrednog okruženja, tako i daljinski. Komunikacione opcije obuhvataju:

- Lokalna komunikacija služi za podešavanje, upravljanje i nadzor nad radom pretvarača, odnosno pogona u celini, sa lica mesta, odnosno na samom pretvaraču. Ovu komandnu jedinicu čini displej, sa tastaturom.
- Digitalni ulazi i izlazi. Pretvarači renomiranih proizvođača imaju više digitalnih ulaza i izlaza, obično na 24VDC, što omogućava razmenu logičkih komandi sa okruženjem.

- Relay inputs and outputs allow the exchange of logical commands at different voltage levels, different from 24VDC.
- Analogous inputs and outputs, which are usually integrated in converter allow control and closing of feedback circuits in order to integrate the converter into the control system. Analogous inputs and outputs may be voltage (0-10VDC) circuit (0-20mA) or impulse.
- Communications protocols - Up-to-date converters are designed to enable the connection with other units within the system and superior control levels etc. via different standard protocols RS232 and RS485, profibus, interbus, device-net, modbus, eternet, etc.

It should particularly emphasise that in case of multiple motor dives it is possible to couple various converters into a unique system that allows distribution of load in line with the possibilities and requirements of particular driving units.

Maintenance and service life - The full name of converter is static frequency converter, which means that there are no movable parts, i.e. there is no wear and tear. The only mobile element is the cooling fan, which switches on only when the temperature in the device rises above specified value. Consequently, converters do not require any maintenance. Considering that control and adjustment are made digitally, the values once set are permanently memorised and do not change in time.

The service life is unlimited, because there is no wear and tear of parts. Failures may occur at the beginning of operation due to hidden technological faults in electronic components. The number of such failures is reduced to minimum if brand name devices are used, such as ABB, Danfoss, Siemens, etc.

3 THE APPLICATION OF FREQUENCY CONVERTERS FOR THE REGULATION OF BELT CONVEYORS

According to DIN 22101 conveyor capacity is calculated on the basis of 80% of belt cross-section utilisation (Figure 3). Extensive investigations that were carried out in Germany show that frequency regulation allows, by means of acceleration during short intervals, the conveyance of fully loaded belts (belt cross-section utilisation 117%). Figure 3 presents the conceptual layout that demonstrates the loading control and the use of frequency regulation of belt conveyors. Figure 4 presents the cross-section of belt utilisation as function of frequency regulation.

- Relejni ulazi i izlazi omogućavaju razmenu logičkih komandi na drugim naponskim nivoima, različitim od 24VDC.
- Analogni ulazi i izlazi koji su uobičajeno integrisani u pretvarač omogućavaju upravljanje i zatvaranje povratnih veza u cilu integrisanja pretvarača u sistem upravljanja. Analogni ulazi i izlazi mogu biti naponski (0-10VDC), strujni (0-20mA), ili impulsni.
- Komunikacioni protokoli. Savremeni pretvarači raspolažu i mogućnošću povezivanja sa drugim jedinicama u sistemu, i nadređenim nivoima upravljanja, skadama itd. preko različitih standardnih protokola, RS232 i RS485, profibus, interbus, device-net, modbus, eternet, itd.

Posebno treba istaći mogućnost sprezanja više pretvarača kod višemotornh pogona u jedinstveni sistem, koji obezbeđuje raspodelu opterećenja u srazmeri sa mogućnostima i potrebama pojedinih pogona.

Održavanje i rok eksploatacije - Pun naziv pretvarača je statički pretvarač učestanosti, što znači da nema pokretnih delova, odnosno habanja. Jedini pokretni element je ventilator za hlađenje, koji se uključuje samo kada se temperatura u uređaju popne iznad određene vrednosti. Prema tome pretvarači ne zahtevaju nikakvo održavanje. Zbog digitalnog načina đupravljanja i podešavanja jedanput podešene vrednosti ostaju trajno zapamćene, bez ikakvih promena u vremenu.

Vreme eksploatacije je neograničeno, jer nema trošenja delova uređaja. Otkazi mogu da se jave u početku eksploatacije zbog skrivenih tehnoloških mana u elektronskim komponentama. Broj ovakvih otkaza je minimalan ako se koriste uređaji renomiranih proizvođača, ABB, Danfoss, Siemens, itd.

3 PRIMENA POGONA SA FREKVENTNOM REGULACIJOM NA TRANSPORTERIMA

Prema DIN 22101 kapacitet transportera se proračunava na osnovu 80% popunjenosti profila trake (slika 3). Obimnim istraživanjima koja su sprovedena u Nemačkoj pokazano je da primenom frekventne regulacije može, u kratotrajnim periodima povećanjem brzine omogućiti transport potpuno napunjene trake (popunjenost profila 117%). Na slici 3 prikazana je principijalna šema kontrole utovara i primene frekventne regulacije na transporterima, a na slici 4 prikazani su profili popunjenosti trake u funkciji frekventne regulacije.

From figure 4 it may be noticed that the use of scanner is anticipated to measure bulk material flow (capacity) both at the excavator and at conveyors. These measurements signalise either acceleration or deceleration of the belt.

Na slici 4 uočava se postojanje skenera za merenje protoka materijala (kapaciteta), kako na samom bageru, tako i na transporterima. Merenjem protoka daje se signal za ubrzavanje ili usporavanje transportera.

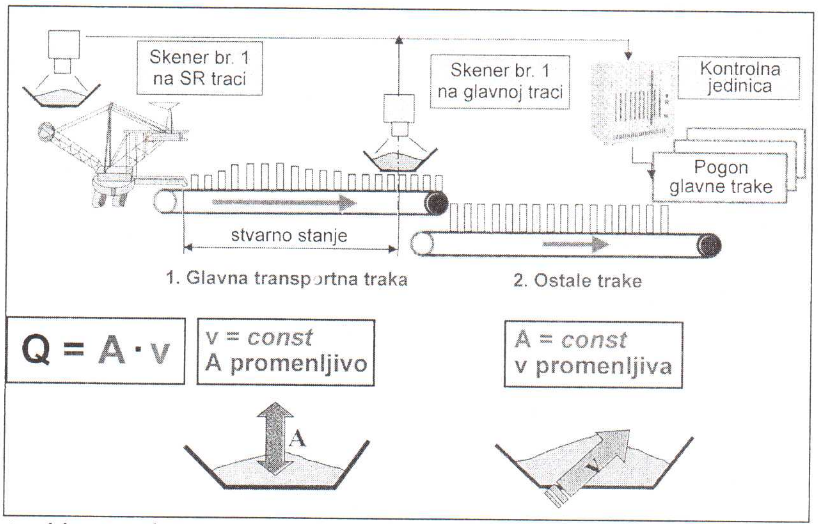

Figure 3 Conceptual layout demonstrating loading control and frequency regulation of belt conveyors
slika 3 Principijalna šema kontrole utovara i primene frekventne regulacije na transporterima

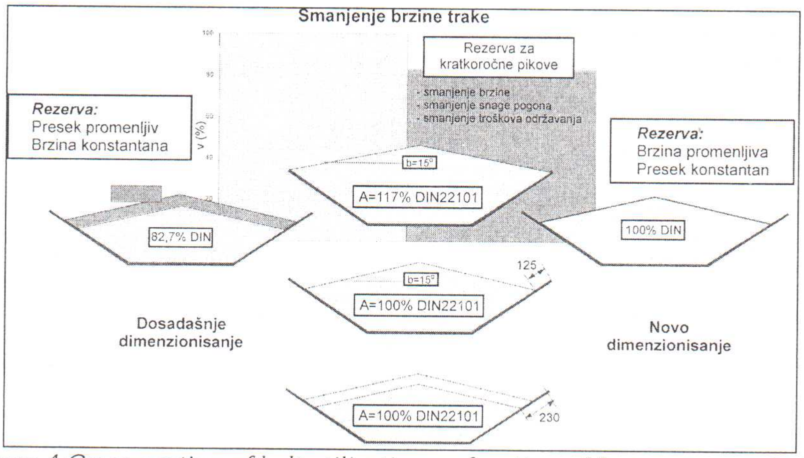

Figure 4 Cross-section of belt utilisation as function of frequency regulation
slika 4 Profili popunjenosti trake u funkciji frekventne regulacije

The effects of frequency regulation have been analysed examining the performance of the SRs 6300 bucket-wheel excavator that operates within a system that includes conveyors with 2.5-m wide belts and 1500 kW of driving power, designed to transport overburden at several large surface mines in Welyow – Sud and Nochten. The initial assumption of the analysis was that capacities that exceed the rated capacity occur only during short intervals of time (several minutes). The primary approach to optimisation was based on the slower belt movement "standard operation" and adjustment to peak capacities by increasing torque to 120%. Table 1 presents the comparison of conveyor features without the use of frequency regulation.

Efekti primene frekventne regulacije su istraživani na primeru rotornog bagera SRs 6300 koji radi u sistemu sa transporterima širine 2.5 m, snage pogona 1500 kW koji su u upotrebi na transportu otkrivke na nekoliko velikih kopova u Welyow – Sud i Nochten. U istraživanju se pošlo od pretpostavke da se kapaciteti veći od nominalnog javljaju samo tokom kratkotrajnih vremenskih intervala (nekoliko minuta). Osnovni koncept pristupa optimizacije se sastojao u kretanju trake smanjenom brzinom u "normalnom radu" i prilagođavanju vršnim kapacitetima povećanjem obrtnog momenta na 120%. U tabeli 1 prikazane su uporedne karakteristike transportera sa i bez frekventne regulacije.

Table 1 Comparison of conveyor features without the use of frequency regulation
Tabela 1 Uporedne karakteristike transportera sa i bez frekventne regulacije

	Conventional conveyor type	Conveyor with frequency regulation
Number of revolutions (1/min)	1000 invariable	1000, variable from 50% to 120%
Capacity/installed power of separate driving units (kW)	1500	2000
Belt speed (m/s)	6.1 invariable	5.2 or 5.5, variable from 50% to 120%
Utilisation of belt cross-section according to DIN 22101	Designed to 80% of standard capacity 15400 m^3rm/h	Designed to 100% for capacity control 7700 to 15400 m^3rm/h
Startup time (s)	8 to 65 s, depending on loading	90s depending on loading
Starting moment	Depending on loading between 1.1 and 1.8, average 1.35	Depending on loading 0.5 to 1.3
Startup efficiency	0.9	0.94
Average annual conveyance speed (m/s)	6.1	$\leq$5.1

The capacity of conveyors without speed regulation depends on the one hand on planned mine output and on the capacity of the loading machinery on the other. The speed of the belt and the dimensions of the cross-section through bulk material on the belt will be such as to provide undisturbed transportation under all working conditions.

For the annual distribution of capacity rates shown in Figure 5 the speed that was adopted was the speed that allows a uniform operation with an acceptable utilisation of the cross-section of about 80%, according to DIN 22101 standard (item 1)

Therefore, the utilisation of the cross-section during a time interval of a few seconds or minutes may increase up to 114%, without causing spillage of material over belt edges. Yet, most of the time the utilisation of cross-section ranges from 50 to 60%, which means that during these periods the speed of conveyance is oversized.

On the other hand, if the driving units are equipped with speed regulation devices, conveyance speed may be adjusted to match the momentary bulk material flow. This way of control that allows bulk density measurement of the material on the belt provides increased utilisation of the cross-section that exceeds 80%.

The next issue is the adjustment of the speed control range to the statistical capacity of the working machine.

Kod transportera bez regulacije brzine kapacitet zavisi od projektovanog kapaciteta kopa sa jedne i od kapaciteta utovarne mehanizacije sa druge strane. Brzina trake i veličina poprečnog preseka materijala na traci će biti takvi da obezbede nesmetani transport pod svim radnim uslovima.

U slučaju raspodele učestalosti kapaciteta tokom godine koja je prikazana na slici 5 usvojena je brzina koja omogućava stabilan rad sa prihvatljivom popunjenošću poprečnog preseka od oko 80%, a u skladu sa DIN 22101 standardom (tačka 1).

Prema tome, popunjenost poprečnog preseka tokom perioda od nekoliko sekundi ili minuta može da se poveća do 114%, a da ne dođe do prosipanja materijala preko ivica trake. Tokom najvećeg dela vremena iskorišćenje poprečnog preseka će se kretati u granicama 50 – 60%, što znači da će tokom ovih perioda brzina transporta biti suviše velika.

U slučaju pogona sa regulacijom brzine, brzina transporta se može podesiti tako da odgovara trenutnom zapreminskom protoku materijala. Ovakav način kontrole pri kome se meri zapremina materijala koja nailazi na traku omogućava povećanje iskorišćenja poprečnog preseka trake preko 80%.

Sledeće pitanje je prilagođavanje raspona kontrole brzine statističkom kapacitetu otkopne mašine.

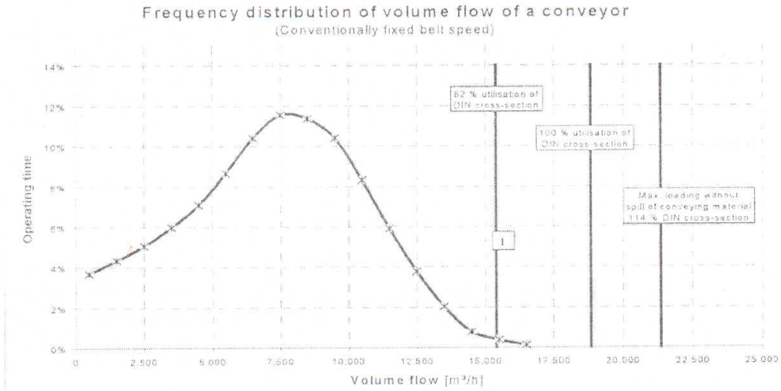

Figure 5 Annual distribution of capacity rates
slika 5 Raspodele učestalosti kapaciteta tokom godine

Bearing in mind that modern drive units are capable of cost-effective operation at speeds ranging from 50 to 100% of the maximum speed, depending on time-limited overheating, it is always advisable to adopt a speed value that is higher than the one usually adopted. In order to guarantee that peak capacities will be met the motor will operate (during short time intervals) exceeding the speed from 15 to 30% of the basic speed value.

The flow rate regulation procedure is presented in figure 6.

Ako se uzme u obzir da savremeni pogonski sistemi mogu da sa malim troškovima rade sa brzinama u rasponu od 50 do 100% maksimalne brzine, u zavisnosti od vremenski ograničenog pregrevanja sistema, potrebno je uvek usvajati veću brzinu od one koja se standardno usvaja. Kako bi se moglo garantovati ostvarenje vršnih kapaciteta, motor će (u kratkim vremenskim intervalima) raditi sa prekoračenjem brzine u rasponu od 15 do 30% osnovne brzine.

Procedura regulacije protoka je prikazana na slici 6.

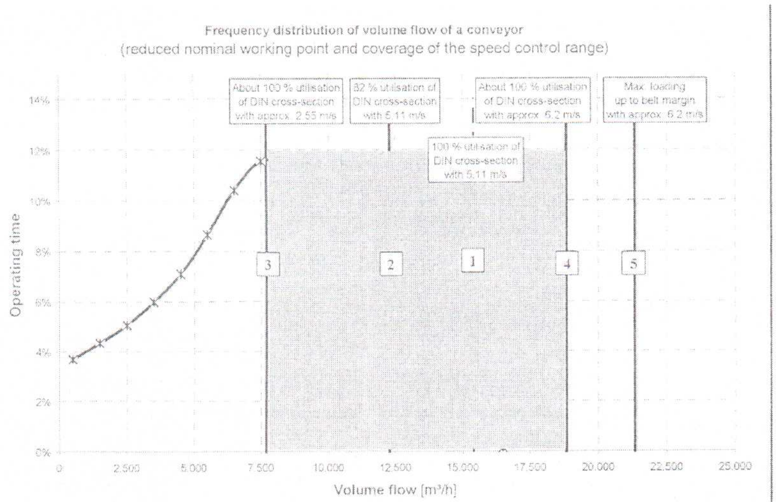

Figure 6 Flow rate regulation procedure
slika 6 Procedura regulacije protoka

In this way the control range may be adjusted to statistical bulk flow rate. To facilitate the determination of speed regulation limits it is possible to define working points that describe the key values of controlled conveyance system in comparison with the conveyor system without speed regulation.

Na ovaj način, raspon kontrole se praktično može prilagoditi statističkom zapreminskom protoku. Kako bi se olakšalo određivanje granica regulacije brzine, mogu se definisati radne tačke koje opisuju ključne vrednosti kontrolisanog transportnog sistema u poređenju sa transporterom bez regulacije brzine.

Point 1: This is, according to the bulk flow rate the point of reference if compared with figure 6. It represents a new basic working point in which the conveyance speed is lower at the same number of revolutions per minute (e.g. 1000 min^{-1}) in comparison with the system presented in figure 5.

It should be emphasised that the achievable bulk flow rate is equal to the example given in figure 1. The utilisation of the cross-section increases from about 82% (Figure 5) to about 100% (point of reference in figure 2), which is in this case acceptable since the belt speed is always adjusted to the newly-coming bulk flow rate (within certain limits). Some segments of the conveyor will be designed in line with larger bulks of material

Point 2: This point represents the resulting bulk material flow rate in case the speed is equal to point 1, but with the now regular utilisation of cross-section of over 82%, according to DIN 22101.

Point 3: The point 3 shows the possibility of belt speed lowering in case of reduced bulk flow rate (> 50% than the rated value), which allows optimum utilisation of cross-section. If the bulk flow rate drops below 50%, the belt speed is furthermore reduced. In these two cases the reduction of belt speed results in reduced consumption of energy and the wear and tear if compared with conveyors without speed regulation.

Point 4: Point 4 features the upper control limit, which is reached by exceeding the rated number of revolutions by 20%. In this case belt speed reaches the value of 6.2 m/s. The temporary achievable bulk flow rate thus reaches its peak capacity of the working machine.

The motor is able to withstand such overload for about 10 minutes on the basis of heat balance. The working machine is very rarely able to achieve these capacities and if so, only for e few seconds. The equipment (electrical and mechanical) must be capable of withstanding brief overloads that occur when speed limit is exceeded.

Point 5: This point has purely theoretical meaning and represents the case of full utilisation of overall belt with from edge to edge.

Shaded area in the diagram presents the control range of the system.

Tačka 1: Ovo je, u odnosu na zapreminski protok, referentna tačka u poređenju sa slikom 6. Ona predstavlja novu osnovnu radnu tačku koja daje manju brzinu transporta pri istom broju obrtaja (npr. 1000 min^{-1}) u poređenju sa sistemom prikazanim na slici 5.

Potrebno je naglasiti da je ostvarivi zapreminski protok materijala isti kao i u slučaju datom na slici 1. Popunjenost poprečnog profila se povećava sa oko 82% (slika 5) na oko 100% (referentna tačka slike 2), što je u ovam slučaju prihvatljivo jer se brzina trake uvek prilagođava dolazećem zapreminskom protoku (u određenjim granicama). Delovi transportera će biti projektovani u skladu sa većim masama materijala koje se nalaze na traci.

Tačka 2: Ova tačka predstavlja rezultujući zapreminski protok materijala u slučaju iste brzine kao u tački 1, ali sa danas uobičajenom popunjenošću poprečnog preseka od oko 82%, po preporuci DIN 22101.

Tačka 3: Tačka 3 pokazuje mogućnost redukovanja brzine trake u slučaju malih zapreminskih protoka (> 50% od nominalnog), čime se omogućava optimalna popunjenost poprečnog preseka. Ukoliko zapreminski protok padne ispod 50%, brzina trake se dalje ne umanjuje. U ova dva slučaja, mala brzina trake rezultuje značajno smanjenom potrošnjom energije i manjim habanjem nego kod transportera bez regulacije brzine.

Tačka 4: Tačka 4 karakteriše gornju granicu kontrole koja se dostiže prekoračenjem nominalnog broja obrtaja za 20%. U ovom slučaju brzina trake dostiže vrednost od 6.2 m/s. Ostvarivi kratkotrajni zapreminski protok ovim već dostiže vršni kapacitet otkopne mašine.

Motor je u stanju da podnese ovakvo preopterećenje u trajanju od oko 10 minuta, na osnovu toplotne ravnoteže. Otkopna mašina je u stanju da da ove kapacitete veoma retko, a i tada samo u trajanju od nekoliko sekundi. Oprema (elektro i mehanička) mora biti u stanju da podnese kratkotrajna preopterećenja koja se javljaju pri prekoračenjima brzine.

Tačka 5: Ova tačka je čisto teorijskog značaja i predstavlja slučaj potpune popunjenosti ukupne širine trake, od ivice do ivice.

Osenčena oblast na dijagramu predstavlja kontrolni raspon sistema.

System dynamics - For longer and wider conveyor belts required torque at the moment of start up may be achieved rationally only by motors with controlled sliding, drives with hydraulic clutches or by means of converters considering large inertial forces that should be handled.

Dynamics depend on acceleration required to increase belt speed to basic value within the time limit set for equipment overloading. In most cases the mean values are 1.3 time higher and the maximum value is 1.8 time higher than the basic value during acceleration when motors with sliding rings and starters with cascade resistors are used.

Maximum statup time of empty belt is 20 sec and it depends on the length of the belt. The startup time of a loaded conveyor belt reaches 1 minute due to thermal limitation of resistors. In case of multiple drives separate drives must be mutually synchronised (motor features, drum diameter).

The synchronisation mainly affects one working point, which changes in line with load variations and wear of drum casing. When the drives operate out of the synchronised point (for example due to load variations) it is not possible to achieve calculated or installed capacity. As a result the system switches off in case of difficult startup and if necessary additional drives are installed or the available ones are oversized.

At the startup an increased torque is gradually introduced, which may cause significant dynamic stress and thus producing additional strain, wear and tear. Temporary gear leaps cause longitudinal vibrations in the belt that produce additional stress in mechanical conveyor components.

Even at low utilisation of belt cross-section the belt will move at designed constant conveyor speeds, which leads to high consumption of energy.

Transmission losses - In case of multiple-drum drive insignificant changes occur in the diameter (up to 2 cm) due to diverse wear of drum casing in the course of their service life.

When overhauls are carried out both drums are usually not replaced at the same time so that the difference in diameters will become even bigger.

Dinamika sistema - Potrebni obrtni momenti prilikom pokretanja za transportere sa većim dužinama i širinama trake mogu biti ostvareni na racionalan način samo sa motorima sa kontrolisanim proklizavanjem, pogonima sa hidrauličkim spojnicama ili pomoću konvertera zbog velikih inercijalnih masa koje je potrebno savladati.

Dinamika zavisi od ubrzanja potrebnog da se brzina trake poveća do osnovne brzine u okviru vremenske granice preopterećenja opreme. Najčešće se javljaju srednje vrednosti 1.3 puta veće, i maksimalna vrednost 1.8 puta veća od osnovne brzine tokom ubrzanja pri korišćenju motora sa kliznim prstenovima i startera sa kaskadnim otpornicima.

Prazna traka ima maksimalno vreme pokretanja od 20 sec, u zavisnosti od dužine. Vreme pokretanja punog transportera kreće se do 1 minuta zbog temperaturnog ograničenja starnih otpornika. U slučaju primene više pogona pojedini pogoni moraju da budu međusobno usklađeni (karakteristike motora i prečnici bubnjeva).

Ova usklađivanja uglavnom utiču na jednu radnu tačku koja se menja u zavisnosti od promene opterećenja i habanja omotača bubnja. Kada pogoni rade van usklađene tačke (na primer usled varijacije u opterećenju), ne može se postići proračunati i instalisani kapacitet. Ovo rezultuje isključivanjem sistema u slučaju teškog pokretanja, ako je neophodno ili instalacijom dodatnih pogona, ili predimenzionisanjem postojećih.

Pri pokretanju dolazi do postepenog uvođenja velikog obrtnog momenta koji može da izazove značajna dinamička naprezanja transportera sa trakom i na taj način ddovede do dodatnog zamora materijala i habanja. Trenutni skokovi između stepena prenosa prouzrokuju longitudinalne vibracije u traci koje izazivaju dodatna optercenja u mehaničkim delovima transportera.

Konstantne brzine transporta zahtevaju da se pri malom iskorišćenju poprečnog preseka traka kreće projektovanom brzinom što dovodi do visoke potrošnje energije.

Gubici u prenosu - U slučaju višebubanjskog pogona javljaju se zanemarljive promene u prečniku (do 2 cm) zbog različitog habanja omotača bubnjeva tokom njihovog radnog veka.

Pri remontu, oba bubnja se uglavnom ne zamenjuju u isto vreme tako da će razlike u prečnicima postati još veće posle zamene jednog od bubnjeva.

In case of asynchronous rotors with sliding rings, which were used until now, the differences between the drums are adjusted by means of permanent sliding resistors. However, this may be applied only in the working point. The variation in the quantity of material at the belt from the working point causes differences between drives. As a result the installed power/capacity and the required acceleration cannot be mechanically transferred to the belt during movement. In practice this is appears as extensive belt slippage.

To overcome the slippage problem the practice until now was to install additional drives, which on the other hand increases electrical losses.

4 SPECIFIC USE OF FREQUENCY CONVERTERS FOR BELT CONVEYORS

The system that operates at the coal surface mine Welzow- South consists of 11 belt conveyors, of which 5 have belt drive regulation with speed range from 3 to 6 m/s Š1Ć. The basic features of these belts are:

Belt KV111, 381m, 1x630kW;
Belt KV112, 225m, 1x630kW;
Belt A113, 910m, 3x900kW;
Belt A114, 152m, 1x900kW;
Belt A105, 1552m, 3x630kW.

The motors used are six-pole, low-voltage for 690V. The conveyors A113 and A105 operate in the system with three inverters with common direct circuit powered by means of one diode rectifier and one reversible transistor rectifier. ABB Company produced the equipment installed. All the possibilities of this method have been put to use and therefore all essential features have been realised:

- Belt speed control, which provides optimum belt utilisation;
- Control of speed, acceleration and deceleration of separate drives;
- Prevention of slippage;
- Uniform loading among drives;
- Energy saving;
- Reduced ware and tear;
- Fewer standstills.

At the same mine specific 2.600-m long conveyor is put in operation, it is capacity is 26.200 t/h, speed range from 3 to 6 m/s [2. Three squirrel-cage asynchronous motors are used each of 2000 kW.

U slučaju asinhronih rotora sa klizajućim prstenovima koji su do sada korišćeni regulisanje karakteristika između oba bubnja upotrebnom stalnih kliznih otpornika. Međutim, ovo je samo primenljivo na radnu tačku sistema. Variranje u količini materijala na traci od radne tačke prouzrokuje razlike između pogona. Rezultat ovoga je da instalirana snaga, a time i potrebno ubrzanje ne mogu biti mehanički preneti na traku tokom pokretanja. U praksi, ovo se manifestuje kao pojačano proklizavanje trake.

Do sada se ovaj problem prevazilazio samo instalacijom dodatnog pogona u kontekstu povećanog proklizavanja a time i povećanih električnih gubitaka.

4 KARAKTERISTIČNE PRIMENE FREKVENTNIH PRETVARAČA NA TRAKASTIM TRANSPORTERIMA

Na ugljenom sistemu kopa Welzow jug nalazi se sistem od 11 transportera, od kojih je pet sa regulisanim pogonima za pogon traka, u opsegu brzina od 3 do 6 m/s Š1Ć. Osnovne karakteristike traka sa regulacijom brzine su:

Traka KV111, 381m, 1x630kW;
Traka KV112, 225m, 1x630kW;
Traka A113, 910m, 3x900kW;
Traka A114, 152m, 1x900kW;
Traka A105, 1552m, 3x630kW.

Svi primenjeni motori su šestopolni, niskonaponski, za napon od 690V. Kod transportera A113 i A105 primenjen je sistem sa tri invertora sa zajedničkim jednosmernim kolom, koje se napaja preko jednog diodnog ispravljača i jednog reverzibilnog tranzistorskog ispravljača. Ugrađena oprema je proizvođača ABB. Iskorišćene su sve mogućnosti ovog načina pokretanja tako da su ostvarene sve bitne karakteristike pogona ovakve vrste:

- Kontrola brzine trake, što obezbeđuje optimalnu napunjenost trake;
- Kontrolu brzine, ubrzanja i usporenja pojedinih pogona;
- Sprečavanje proklizavanja;
- Ujednačavanje opterećenja između pogona;
- Ušteda energije;
- Smanjenje habanja opreme;
- Smanjene zastoja.

Na istom kopu primenjen je i transporter dugačak 2.600 m, kapaciteta 26.200 t/h, sa brzinom u opsegu 3 do 6 m/s [2]. Upotrebljena su četiri kavezna asinhrona motora snage od po 2000 kW.

Each motor is powered from medium-voltage converters of 3100 kVA and controllable reversible rectifiers are installed to the network. The achieved energy saving is estimated to 20%. SIEMENS equipment was used.

To transport bauxite to the aluminium foundry in Western Australia (Worsley Alumina Refinery) is carried out via two belt conveyors each 50km long [3]. Maximum conveying speed is 7 m/s. The first belt is 30km long; the transport rout has several ascents and descents. Two frontal motors each of 3300kW and two rear motors each of 1700kW drive the belt. The second belt is 20km long and it is driven by two motors each 3300kW. The converters are medium-voltage (3,3kV), standard ABB series ACS1000.

5 CONCLUSION

Drives with frequency regulation allow significant improvements of mining operations. Considering the vast advantages that this technology offers with respect to the application of control elements the below stated shortcomings such as:

- transmission losses in case of multiple-drum drives,
- high dynamic stress at startups and braking,
- increased consumption of energy and wear and tear during periods in which the designed basic speed is exceeded,
- higher initial investment and operation costs due to oversize and
- increased wear of systems without speed control

may be avoided and/or offset to a considerable extent in a longer period of time. The use of frequency regulation allows considerable reductions in energy costs between 7 and 24%. Maintenance costs can be cut down up to 14% if compared with conveyors without speed control depending on the resulting mean annual speed.

It should be pointed out that this system is still in development stage and that the initial investment costs are still to high. Apart from this the stoppers at the transfer points should be automatically adjustable in order to provide continuous transference, high-power driving units should be provided along with transformer stations at the site and ventilated premises. In spite of this it is likely to expect problems with energy control and turning back to the network and the existence of harmonicas at high powers.

Svaki motor se napaja iz srednjenaponskog pretvarača od 3100 kVA. Prema mreži postavljeni su upravljivi reverzibilni ispravljači. Procenjuje se da ostvarena ušteda energije iznosi do 20%. Korišćena je SIEMENS-ova oprema.

Za dopremanje boksita do aluminijumskog kombinata u zapadnoj Australiji (Worsley Alumina Refinery) primenjen je sistem od dve trake ukupne dužine od 50km [3]. Maksimalna brzina transporta je 7m/s. Prva traka je dugačka 30km, sa profilom trase sa nekoliko uspona i padova. Pogon trake ostvaruju dva čeona motora od po 3300kW, i dva repna motora od po 1700kW. Druga traka je dugačka 20km, i pokreću je dva motora od po 3300kW. Pretvarači su srednjenaponski (3,3kV) standardne ABB serije ACS1000.

5 ZAKLJUČAK

Primenom pogona sa frekventnom regulacijom moguće je postići značajna poboljšanja u eksploataciji. Zbog vlikih pogodnosti koje pruža ova tehnologija po pitanju korišćenja kontrolnih elemenata, navedeni nedostaci kao što su:

- gubici u prenosu kod višebubanjskih pogona,
- visoka dinamička neprezanja kod pokretanja i kočenja,
- visoka potrošnja energije i habanje u onim periodima vremena kada je projektovana osnovna brzina prevelika,
- veća investiciona ulaganja i operativni troškovi zbog predimenzionisanosti i
- intenzivnihe habanje kod sistema bez kontrole brzine

mogu biti izbegnuti i/ili velikim delom umanjeni u dužem vremenskom periodu. Korišćenjem frekventne regulacije može se ostvariti umanjenje u troškovima energije između 7 i 24% . Troškovi održavanja mogu biti umanjeni do 14% u poređenju sa transporterima bez kontrole brzine u zavisnosti od rezultujuće prosečne godišnje brzine.

Treba naglasisiti da je ovaj sistem još uvek u fazi razvoja i da su još uvek dosta veći investicioni troškovi za nabavku ovih transportera. Pored toga potrebno je da »klapne« na presipnim mestima budu automatski podesive kako bi se osigurao stalan presip, zatim zahtevaju pogonsku grupu nešto veće snage, transformatore na licu mesta sa klimatiziranim prostorijama, a pored toga mogući su problemi sa kontrolom i vraćenjem energije u mrežu i postojanje harmonika u mreži pri velikim snagama.

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