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CERTAIN ASPECTS OF PIPELINE BELT CONVEYOR USE FOR SIMULTANEOUS TRANSPORTATION OF COAL AND ASH

NEKI ASPEKTI PRIMENE CEVASTIH TRANSPORTERA SA TRAKOM ZA ISTOVREMENI TRANSPORT UGLJA I PEPELA

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Abstract: *Large-scale ore production represents a specific feature of modern mining. On the other hand a growing demand for environmental protection is becomes imposingly important. As a result, state-of-the-art technological solutions are being applied in contemporary mining in order to enable large-scale production and a high degree of environmental protection. Pipeline belt conveyors are considered to be one of the systems that are able to cope with both demands. This paper provides some examples illustrating the use of this conveyance method and defines some specific states of stress that occur in the belt during conveyance.*

Key words: *transportation, environmental protection, coal, ash, pipeline belt conveyor*

Apstrakt: *Masovna proizvodnja mineralnih sirovina predstavlja jednu od karakteristika savremenog rudarstva. Sa druge strane su sve prisutniji zahtevi za zaštitu životne sredine. Zbog toga se i u rudarstvu uspešno primenjuju nova tehnološka rešenja koja omogućuju visoke proizvodne kapacitete i visok stepen zaštite životne sredine. Kao postrojenja koja ispunjavaju oba uslova mogu se smatrati cevasti transporteri. U ovom radu se daju neki primeri primene ovog načina transporta, kao i definisanje nekih karakterističnih napona koji se javljaju u traci prilikom transporta.*

Ključne reči: *transport, zaštita životne sredine, ugalj, pepeo, cevasti transporteri*

1. INTRODUCTION

In the course of ore conveyance the environment is endangered due to the pollution caused by material spillage along the route. This form of pollution represents a big problem, especially during the transportation of fine-grained and powdery materials particularly in areas with powerful winds. It is especially pronounced at transfer points, in continuous conveying systems, namely at loading or reloading points or in discontinuous or cyclic conveyance.

1. UVOD

Prilikom transporta mineralnih sirovina životna sredina je ugrožena usled zagađenja koje nastaje, najčešće, kontaktom između atmosfere i materijala, kao i zbog prosipanja tereta duž trase. Ova zagađenja, naročito kod sitnokomadastog i prašinastog materijala, u područjima sa jakim vetrovima, predstavljaju veliki problem. To je, naročito, izraženo na presipnim mestima, kod kontinualnih transportnih sistema, odnosno, na mestima utovara ili istovara kod cikličnog transporta.

The use of pipeline belt conveyors is environmentally safe since it is able to eliminate a series of noxious effects. However, over the last few years, these conveyors have been increasingly used also for ore conveyance taking into account their following advantages:

- high-capacity performance (up to 800 t/h),
- efficient mastering of slopes if compared to standard belt conveyors (up to 40°),
- pipe-enclosed belt prevents the interaction between conveyed material and atmosphere,
- reversible conveyance of material,
- obstacles may be bypassed without transfer points by taking curves in horizontal plane,
- high automation potentials etc.

The aim of this paper is to consider different possibilities of use of reversible pipeline conveyors for external conveyance. Particular attention is paid to simultaneous transportation of coal towards the coal-fired power plant and of ash in the opposite direction. The paper also analyses the state of stress that occurs when the belt is being enclosed into pipe or when it goes into curvilinear.

2. CAPABILITIES OF PIPELINE BELT CONVEYORS FOR REVERSIBLE TRANSPORTATION OF COAL AND ASH

Apart from these advantages it must be also mentioned that the same parts and assembly blocks used for standard belt conveyors may be also used for pipeline conveyors. These are in the first place: driving stations, return stations, tensioning sections, loading and reloading devices and sections, rollers and structures at the on-going spread sections of the belt etc. Compared with standard conveyors the pipeline conveyors may also have driving stations along the route, multiple loading and standard tensioning. The consumption of energy per unit of conveyed product is approximately equal, or sometimes even lower than the consumption determined for standard conveyors.

Among the disadvantages that are characteristic for this type of conveyance the following may be noted: considerably lower grain-size range of conveyed material, wear and tear susceptibility, problems that appear during belt pipe-enclosing and difficulties in achieving and maintaining the lateral belt elasticity. The previously mentioned drawbacks may be eliminated with more or less success by implementing corresponding

Primenom cevastih transportera sa trakom eliminišu se mnoge štetne pojave i uticaji na okolinu. Poslednjih godina ovi transporteri, sve više primenjuju i za transport mineralnih sirovina zahvaljujući sledećim osobinama, a to su:

- mogućnost ostvarivanja visokog kapaciteta (do 8000 t/h),
- savladavanje većih uglova nagiba od klasičnih transportera sa trakom (do 40^0),
- onemogućavanje kontakta materijala sa atmosferom zatvaranjem trake u obliku cevi,
- mogućnost reverzibilnog transporta materijala,
- obilaženje prepreka bez presipnih stanica, zahvaljujući savladavanju krivina u horizontalnoj ravni
- mogućnost ostvarivanja visokog stepena automatizacije itd.

Cilj ovog rada je da razmotri mogućnosti primene reverzibilnih cevastih transportera za spoljašnji transport sa posebnim osvrtom na istovremeni transport uglja do termoelektrana i pepela u suprotnom smeru. Takođe, u radu se analiziraju i naponi u traci prilikom njenog savijanja u cev i u krivini.

2. MOGUĆNOSTI PRIMENE CEVASTIH TRANSPORTERA ZA REVERZIBILNI TRANSPORT UGLJA I PEPELA

Prednost cevastih transportera se ogleda i u tome što se upotrebljava dosta delova i sklopova kao kod standardnih transportera sa trakom. Tu, pre svega, spadaju: pogonska stanica, povratne i zatezne stanice, uređaji i delovi za utovar i pretovar, valjci i konstrukcije na razvijenom delu trake i dr. U odnosu na klasične transportere, cevasti transporteri mogu, takođe, da imaju pogonske stanice duž trase, da imaju višestruki utovar i normalno zatezanje. Potrošnja energije po jedinici prevezenog proizvoda je približno ista kao kod klasičnih transportera, u nekim slučajevima, čak, i manja.

Nedostaci cevastih transportera se ogledaju, pre svega, u relativno manjoj granulaciji materijala, osetljivosti trake na habanje, teškoćama pri zatvaranju trake u cev, kao i postizanju i održavanju poprečne elastičnosti trake. Svaki od ovih nedostataka trake se, sa manje ili više uspeha, technological or structural changes during manufacturing or application.

In mining industry the pipeline conveyors are mostly used for the following purposes:

- To transport coal from the mine towards coal-fire power plants, when there is a possibility of reverse transportation of ash, which is to be dumped into excavated spaces.
- In metallic ore mines to transport ore from primary crushing to the flotation plant.
- In conditions of internal conveyance within the mining industrial centres, flotation, separation plants etc.
- In opencast mines of non-metallic ore to transport ore towards primary processing plants.
- In mines and industries that produce cement, clay, lime etc.

In Yugoslav conditions, in large basins called Kolubara and Kostolac, over 95% of coal, which is burnt in 5 steam power plants, are produced. Steam power plants are located near open pits (the biggest distance is 26 km). Both of mining basins are placed in quite settled and agricultural areas with great potentials. There are large degraded surfaces and they make primary and secondary bad effects on surroundings.

Deposition of ashes and slag near steam power plants has increased in enormous extent, so that over 1500 ha of fertile soil. Besides, the ashes is a big source of pollution of air, particularly as the both of the energetic basins are in the areas known for strong winds. There is a big amount of ashes in lignite coals (from 17 to 18.5 %) so that we can assume that this problem will be getting worse in future. There are some average amounts of extracted ashes in steam power plants in these two basins a year given in table 1.

otklanja uz pomoć konstruktivnih i tehnoloških mera u fazi proizvodnje ili primene.

U rudarstvu cevasti transporteri se najčešće primenjuju ili postoje uslovi za njihovu primenu:

- pri transportu uglja od rudnika do termoelektrana, gde postoji mogućnost povratnog transporta pepela radi njegovog deponovanja u otkopane prostore,
- u rudnicima metaličnih mineralnih sirovina za transport od primarnog drobljenja rude do flotacijskih pogona,
- u uslovima unutrašnjeg transporta u rudničkom krugu, flotacijama, separacijama i sl.,
- na površinskim kopovima nemetaličnih mineralnih sirovina za transport do pogona za primarnu preradu,
- u rudnicima i industriji cementa, gline, kreča i sl.

U jugoslovenskim uslovima u dva velika basena Kolubara i Kostolac dobija se preko 95% uglja koji se sagoreva u 5 temoelektrana. Oba rudarska basena se nalaze u gusto naseljenim i poljoprivrednim područjima sa značajnim potencijalom. Degradirane površine su velike i izazivaju primarne i sekundarne štetnosti po okolinu.

Deponovanje pepela i šljake u blizini termoelektrana dostiglo je takve razmere da je u ovom trenutku prekriveno preko 1500 ha plodnog poljoprivrednog zemljišta. Pored toga, pepeo predstavlja veliki izvor zagađenja vazduha, naročito zato što se oba energetska basena nalaze u područjima koja su poznata po jakim vetrovima. Lignitski ugljevi imaju znatan sadržaj pepela (od 17 do 18.5 %), pa je pretpostavka da će se ovaj problem u narednom periodu još više potencirati. U tabeli 1 date su prosečne godišnje količine izdvojenog pepela po termoelektranama u ova dva basena.

Table 1 The average amounts of extracted ashes
Tabela 1 Prosečne količine izdvojenog pepela

System Power Plants	TENT A	TENT B	Kolubara A	Kostolac A	Kostolac B
Coal comsuption in the 1000 t/year	12.000	10.000	2.500	2.400	4.200
Amount of the eshes in 1000 t/year	1.750	1.560	600	600	1.000

In developed countries near 50% of the ashes are used in various fields of civil engineering and industry. Its application in Yugoslavia hardly reaches 5%, and to say it precisely, it is applied in cement production. Subsequently, it is necessary to deposit the ashes as waste to some safe place and to perform its solidification.

Possibility of deposition of the ashes in excavated spaces of open pits appear to be a logical solution. On that account, it is necessary to make some preparations and define the parameters of those inside waste dumps (cassettes, way of solidification, reutilization, etc.). There are 7 open pits with volume of many hundreds of millions of m* of free excavated spaces in five steam power plants' zones (the sixth are being built), with power of approximately 4200 MW. A part of that space have been being permanently fulfilled, but there is still plenty of space for the deposition.

One of the crucial problems in process of deposition of the ashes is transportation from steam power plants, or temporary waste dumps in their circle, to permanent waste dumps. While solving this problem, according to possibilities, some variants should be considered:

- belt conveyors with wet ashes,
- hydraulic transportation with watery and thick mixture,
- railway transportation,
- return belt of coal conveyors,
- pipe belt conveyors, etc.

Preliminary analysis of ash transportation methods [2], indicates that optimum results may be achieved if the hydraulic transportation of dense pulp is combined with the pipeline belt conveyance. Considering the fact that pipeline belt conveyors may be used for simultaneous coal conveyance, due to their reversible operating capacity, it becomes obvious that this way of transportation has excellent prospects.

Figure 1 displays the layout of a possible reversible transportation system with pipeline conveyors in a mining-power supply basin with 4 open cast mines and 4 coal-fired power plants.

Basic shortages of pipe belt conveyors are the following:

- they are more expensive than classical belt conveyors,
- it takes less granulation of pieces,

U razvijenim zemljama se blizu 50% pepela koristi u raznim oblastima građevinarstva i industrije. U Jugoslaviji njegova primena dostiže jedva 5%, i to u proizvodnji cementa. Pepeo kao otpad, prema tome, je neophodno deponovati na bezbedno mesto i pri tome izvršiti njegovu solidifikaciju (očvršćavanje).

Kao logično rešenje nameće se mogućnost deponovanja pepela u otkopane prostore površinskih kopova. U tu svrhu je potrebno izvršiti određene pripreme i definisati parametre tih unutrašnjih odlagališta pepela (kasete, način očvršćavanja, rekultivacija i sl.). U zonama navedenih 5 termoelektrana (šesta je u izgradnji), sa snagom oko 4200 MW, nalaze se 7 površinskih kopova sa zapreminom od više stotina miliona m^3 slobodnog otkopanog prostora. Deo tog prostora se u okviru tehničke rekultivacije permanentno zapunjava, ali, i pored toga,, postoji dovoljno prostora za deponovanje.

Jedan od osnovnih problema u procesu deponovanja pepela je transport od termoelektrana, ili privremenih deponija u njihovom krugu, do trajnih odlagališta. Prilikom rešavanja ovog problema, a prema realnim mogućnostima, trebalo bi razmotriti sledeće varijante:

- transporteri sa trakom sa kvašenim pepelom,
- hidraulički transport sa retkom i gustom mešavinom,
- železnički transport,
- povratna traka transportera za ugalj,
- cevasti transporteri sa trakom i dr.

Preliminarnom analizom navedenih varijanti transporta pepela [2], došlo se do zaključka da se najbolji rezultati mogu postići primenom hidrauličkog transporta sa gustom mešavinom i cevastih transportera sa trakom. S obzirom na činjenicu da se cevasti transporteri, zahvaljujući sposobnostima reverzibilnog rada, mogu koristiti i za istovremeni transport uglja, onda postaje jasno da ovaj način transporta ima značajnu perspektivu.

Na slici 1 je prikazana moguća šema jednog reverzibilnog transportnog sistema sa cevastim transporterima u rudarsko-energetskom basenu sa 4 površinska kopa i 4 termoelektrane.

Osnovni nedostaci cevastih transportera sa trakom su:

- veća cena nego kod klasičnih transportera,
- potrebna je manja granulacija komada,

- special quality of the belt, regarding elasticity, rupture strength and abrasive strength,
- Placement of special dust separators at loading-unloading points, and etc.

- poseban kavalitet trake u pogledu elastičnosti, zatezne čvrstoće i otpornosti na habanje,
- postavljanje posebnih uređaja za otprašivanje na utovarno-istovarnim punktovima i dr.

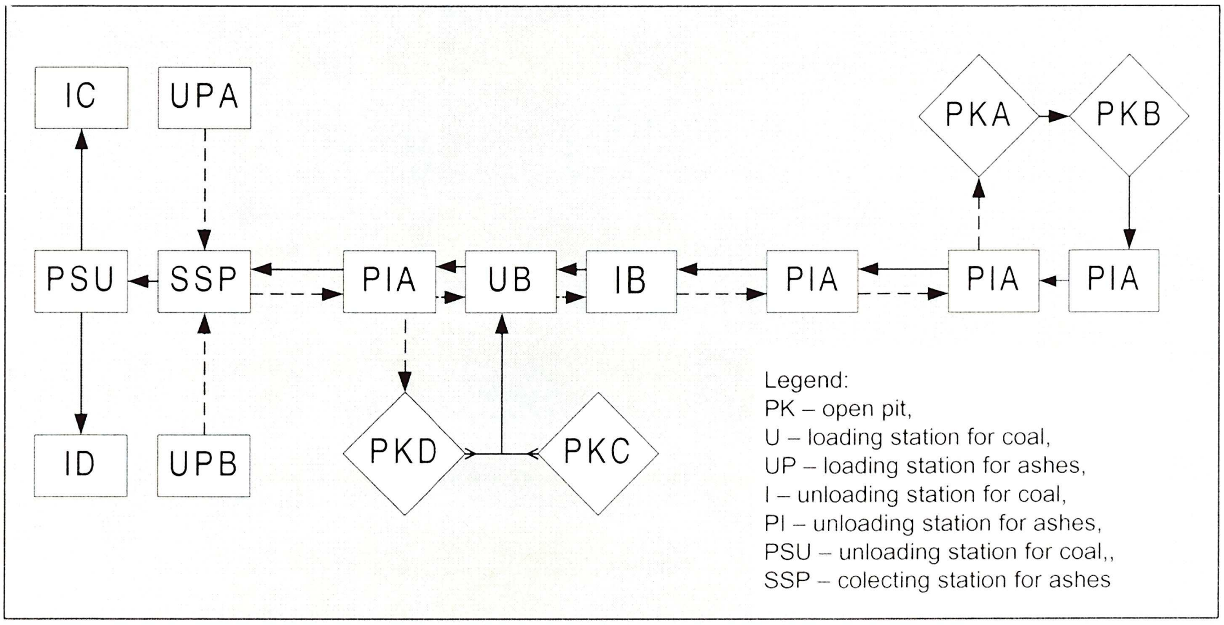

Figure 1 Shema of reversible transportation system with pipeline conveyors
Slika 1 Šema reverzibilnog transportnog sistema za transport uglja i pepela

Initially, the higher price of pipeline conveyors in comparison to conventional conveyors seems like an economic disadvantage yet it is largely compensated through lower overall of transportation coal and ash costs. Moreover, considering the reduced expenses for environmental protection it may be stated that this transportation method is highly cost-effective.

In most cases, coal-crushing plants are installed at the beginning of the system that transports coal towards coal-fired power plants. In this way it is possible to avoid the drawback imposed by the demand for lower grain-size range of conveyed material. In fact, ash falls into the category of fine-grained material.

Every continuous transportation system is provided with dust suppression devices at loading and reloading points, which incurs additional costs. Introducing special additives (foams etc.) these costs may be considerably reduced.

Particular quality of the conveying belt with respect to elasticity, tensile strength and wear-resistance is achieved by adapting the belt parameters to the mining conditions. In order to reach this goal it is necessary to analyse the states of stress that occur in the belt in the course of its movement.

Nedostatak, koji se tiče veće cene cevastih od klasičnih transportera, se u dobroj meri kompenzuje nižim ukupnim troškovima transporta uglja i pepela. Ako se tome dodaju i smanjeni troškovi zaštite životne sredine, onda se može konstatovati da ovaj način transporta spada u visoko ekonomične.

Kod transporta uglja za potrebe termoelektrana, često se drobilane za usitnjavanje uglja nalaze na početku transportnih sistema. Na taj način se eliminiše nedostatak usled potreba manje granulacije materijala. Pepeo, inače, spada u grupu sitnozrnastih materijala.

Dodatni troškovi na utovarno-istovarnim punktovima, zbog postavljanja posebnih uređaja za otprašivanje, se javljaju kod svih kontinualnih transportnih sistema. Dodavanjem posebnih aditiva u materijale (pena i sl.) ovi se troškovi mogu dodatno smanjiti.

Poseban kvalitet transportne trake u pogledu elastičnosti, zatezne čvrstoće i otpornosti na habanje se postiže prilagođavanjem parametara trake uslovima eksploatacije. Da bi se to postiglo neophodno je analizirati napone koji se javljaju u traci prilikom njenog kretanja.

3. THE STATE OF STRESS IN THE BELT DURING PIPE-ENCLOSING

The bending of the belt produces the state of stress in it, which is different from the stress in the normal on-going spread form. For a successful utilization of the belt it is necessary to determine the state of stress in the belt. At this moment the following model is suggested: the section of the belt, which is assumed to be completely covered with firm, rigid material is analyzed. The bending moments (M) and the forces (N) act upon the ending sections of the belt. (Figure 2).

3. NAPONSKO STANJE U TRACI KOJA SE SAVIJA U CEV

Prilikom savijanja trake javljaju se naponi u njoj, koji se razlikuju od napona u normalnom, razvijenom obliku. Da bi se trake mogle sa uspehom primeniti, potrebno je definisati stanje napona u traci. U ovom trenutku predlaže se sledeći model: posmatra se deo trake, za koji se pretpostavlja da je potpuno ispunjen krutim materijalom. Na krajevima trake deluju momenti (M) i sile (N) (slika 2).

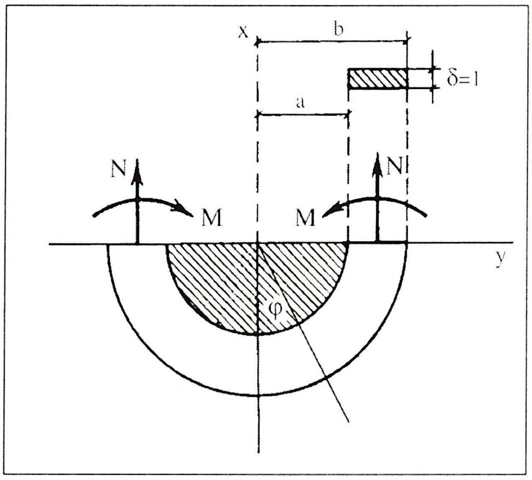

Figure 2 Chart presenting the bending of one belt section
Slika 2 Šema savijanja dela trake

The belt is made of elastic material and it is assumed that it moves in a straight-line direction at a constant speed. Therefore, this problem may be considered as a quasi-static issue. In this case the momentum has the following form:

$$t_{ij,j} + \rho f_i = \rho \frac{\partial^2 u_i}{\partial t^2} = 0 \qquad (1)$$

where:
$t_{ij,j}$ - stress tensor,
f_i - body force,
ρ - density,
u_i - displacement vector,
t - time.

In this case the convention of summation for the repeated index has been used.

Considering the shape of the body for which the state of stress is required it is suitable to use cylindrical coordinates. It must be also noted that for the issue analyzed here a plane state of stress is assumed. Under such conditions the equation (1) becomes:

Traka je napravljena od elastičnog materijala i pretpostavlja se da se kreće pravolinijski, konstantnom brzinom. Zbog toga se može ovaj problem posmatrati kao kvazi-statički. U tom slučaju, zakon količine kretanja ima oblik:

$$t_{ij,j} + \rho f_i = \rho \frac{\partial^2 u_i}{\partial t^2} = 0, \qquad (1)$$

gde su:
$t_{ij,j}$ - tenzor napona,
f_i - zapreminske sile,
ρ - gustina,
u_i - vektor pomeranja i
t - vreme.

Ovde je korišćena konvencija o sabiranju po ponovljenom indeksu.

Zbog oblika tela, čije se naponsko stanje traži, pogodno je koristiti cilindrične koordinate. Važno je napomenuti još i da se za posmatrani problem može smatrati da postoji ravno stanje napona. Pod ovim uslovima jednačina (1) postaje:

$$\frac{\partial t_{rr}}{\partial r}+\frac{1}{r}\frac{\partial t_{r\varphi}}{\partial\varphi}+\frac{t_{rr}-t_{\varphi\varphi}}{r}+F_r=0\,, \qquad (2)$$

$$\frac{\partial t_{r\varphi}}{\partial r}+\frac{1}{r}\frac{\partial t_{\varphi\varphi}}{\partial\varphi}+\frac{2}{r}t_{r\varphi}+F_\varphi=0\,, \qquad (3)$$

In continuation the volumetric forces F_φ and F_r will be ignored. It has also been assumed that the stress tensor is symmetrical while the non-local effect is also ignored.

If the stress function $f(r,\varphi)$ is introduced now, which is considered to be biharmonic, i.e.:

$$\nabla^2\nabla^2 f=0\,, \qquad (4)$$

the stress components may be presented in the form of

$$t_{rr}=\frac{1}{r}\frac{\partial f}{\partial r}+\frac{1}{r^2}\frac{\partial^2 f}{\partial\varphi^2}\,, \qquad (5)$$

$$t_{\varphi\varphi}=\frac{\partial^2 f}{\partial r^2}\,, \qquad (6)$$

$$t_{r\varphi}=t_{\varphi r}=-\frac{1}{r}\frac{\partial}{\partial\varphi}\left(\frac{\partial f}{\partial r}-\frac{f}{r}\right) \qquad (7)$$

Apart from the equations (2) and (3) the stress components have to satisfy with the boundary conditions:

for $r=a\,,\ t_{r\varphi}=0\,,$ (8)

for $r=b\,,\ t_{r\varphi}=t_{rr}=0\,,$ (9)

for $\varphi=\pm\pi/2,\ \int_a^b t_{\varphi\varphi}dr=N,\ \int_a^b t_{\varphi r}rdr=M\,,$

$t_{r\varphi}=0\,,$ (10)

The solution of the equation (4) is

$$f=\left(Ar^{\lambda}+Br^{\lambda+2}+Cr^{-\lambda}+Dr^{-\lambda+2}\right)\cos\lambda\varphi\,, \qquad (11)$$

where λ is an undetermined parameter, which is as the constants A, B, C and D determined according to the boundary conditions (8), (9) and (10):

$$\frac{\partial t_{rr}}{\partial r}+\frac{1}{r}\frac{\partial t_{r\varphi}}{\partial\varphi}+\frac{t_{rr}-t_{\varphi\varphi}}{r}+F_r=0\,, \qquad (2)$$

$$\frac{\partial t_{r\varphi}}{\partial r}+\frac{1}{r}\frac{\partial t_{\varphi\varphi}}{\partial\varphi}+\frac{2}{r}t_{r\varphi}+F_\varphi=0\,, \qquad (3)$$

Nadalje će biti zanemarene zapreminske sile F_φ i F_r. Takođe se pretpostavlja da je tenzor napona simetričan i zanemaruju se nelokalni efekti.

Ako se sada uvede naponska funkcija $f(r,\varphi)$, koja je biharmonijska, tj.:

$$\nabla^2\nabla^2 f=0\,, \qquad (4)$$

komponente napona mogu da se predstave u obliku

$$t_{rr}=\frac{1}{r}\frac{\partial f}{\partial r}+\frac{1}{r^2}\frac{\partial^2 f}{\partial\varphi^2}\,, \qquad (5)$$

$$t_{\varphi\varphi}=\frac{\partial^2 f}{\partial r^2}\,, \qquad (6)$$

$$t_{r\varphi}=t_{\varphi r}=-\frac{1}{r}\frac{\partial}{\partial\varphi}\left(\frac{\partial f}{\partial r}-\frac{f}{r}\right) \qquad (7)$$

Pored jednačina (2) i (3) naponi moraju da zadovolje i granične uslove

za $r=a\,,\ t_{r\varphi}=0\,,$ (8)

za $r=b\,,\ t_{r\varphi}=t_{rr}=0\,,$ (9)

za $\varphi=\pm\pi/2,\ \int_a^b t_{\varphi\varphi}dr=N,\ \int_a^b t_{\varphi r}rdr=M\,,$

$t_{r\varphi}=0\,,$ (10)

Rešenje jednačine (4) je oblika

$$f=\left(Ar^{\lambda}+Br^{\lambda+2}+Cr^{-\lambda}+Dr^{-\lambda+2}\right)\cos\lambda\varphi\,, \qquad (11)$$

gde je λ neodređeni parametar, koji se kao i konstante A,B,C,D određuje iz graničnih uslova (8), (9) i (10):

$$t_{rr} = \left[A\left(\lambda-\lambda^2\right)r^{\lambda-2} + B\left(\lambda+2-\lambda^2\right)r^{\lambda} - C\left(\lambda-\lambda^2\right)r^{-\lambda-2} + D\left(-\lambda+2-\lambda^2\right)r^{-\lambda}\right]\cos\lambda\varphi$$

$$t_{r\varphi} = \left[A\left(-\lambda+\lambda^2\right)r^{\lambda-2} + B\left(\lambda+\lambda^2\right)r^{\lambda} - C\left(\lambda+\lambda^2\right)r^{-\lambda-2} + D\left(\lambda-\lambda^2\right)r^{-\lambda}\right]\sin\lambda\varphi$$

$$t_{r\varphi}\big|_{r=a} = 0 = \left[A\left(-\lambda+\lambda^2\right)a^{\lambda-2} + B\left(\lambda+\lambda^2\right)a^{\lambda} - C\left(\lambda+\lambda^2\right)a^{-\lambda-2} + D\left(\lambda-\lambda^2\right)a^{-\lambda}\right]\sin\lambda\varphi = 0$$

$$t_{r\varphi}\big|_{r=b} = 0 = \left[A\left(-\lambda+\lambda^2\right)b^{\lambda-2} + B\left(\lambda+\lambda^2\right)b^{\lambda} - C\left(\lambda+\lambda^2\right)b^{-\lambda-2} + D\left(\lambda-\lambda^2\right)b^{-\lambda}\right]\sin\lambda\varphi = 0$$

$$t_{r\varphi}\big|_{\varphi=\pm\pi/2} = 0 = \left[A\left(-\lambda+\lambda^2\right)r^{\lambda-2} + B\left(\lambda+\lambda^2\right)r^{\lambda} - C\left(\lambda+\lambda^2\right)r^{-\lambda-2} + D\left(\lambda-\lambda^2\right)r^{-\lambda}\right]\sin\lambda\frac{\pi}{2} = 0$$

$$\Rightarrow \sin\lambda\frac{\pi}{2} = 0 \Rightarrow \lambda\frac{\pi}{2} = k\pi \Rightarrow \lambda = \lambda_k = 2k, k = 0, \pm1, \pm2, \ldots$$

$$t_{rr}\big|_{r=b} = \left[A\left(\lambda-\lambda^2\right)b^{\lambda-2} + B\left(\lambda+2-\lambda^2\right)b^{\lambda} - C\left(\lambda-\lambda^2\right)b^{-\lambda-2} + D\left(-\lambda+2-\lambda^2\right)b^{-\lambda}\right]\cos\lambda\varphi = 0$$

$$\int_a^b t_{\varphi r} r dr = M \Rightarrow$$

$$\int_a^b \left[A\left(-\lambda+\lambda^2\right)r^{\lambda-1} + B\left(\lambda+\lambda^2\right)r^{\lambda+1} - C\left(\lambda+\lambda^2\right)r^{-\lambda-1} + D\left(\lambda-\lambda^2\right)r^{-\lambda+1}\right]\sin\lambda\varphi dr = M$$

$$\Rightarrow \left[A(\lambda-1)\left(b^{\lambda}-a^{\lambda}\right) + B\frac{\lambda(\lambda+1)}{\lambda+2}\left(b^{\lambda+2}-a^{\lambda+2}\right) + C(\lambda+1)\left(b^{-\lambda}-a^{-\lambda}\right) + D\frac{\lambda(\lambda-1)}{\lambda-2}\left(b^{-\lambda+2}-a^{-\lambda+2}\right)\right]\sin\lambda\varphi = M$$

According to the condition $(10)_3$ it follows that

$$\lambda = 2k,\ k = 0, \pm1, \pm2, \ldots$$

Consequently, there is an infinite number of values λ_k. According to the arbitrary λ_k and according to the remaining conditions the constants A_k, B_k, C_k, and D_k will be determined. On the basis of the principle of superposition it will be possible to determine the stress function f.

$$f = \sum_{k=0}^{\infty} f_k = \qquad (12)$$
$$= \sum_{k=0}^{\infty}\left(A_k r^{\lambda_k} + B_k r^{\lambda_k+2} + C_k r^{-\lambda_k} + D_k r^{-\lambda_k+2}\right)\cos\lambda_k\varphi$$

The requested state of stress is obtained.

By applying the Hooke's law it is possible to determine the field of displacement for the assignment observed here.

Finally, it should be emphasized that the given model is to be tested in practice and if necessary, accordingly adjusted. For example, instead of the previously used rigid material it is advisable to observe also the behavior of solid or seepage material. Moreover, it is possible to consider the weight and the dynamic effects that occur on account of the motion and closure of the belt.

Iz uslova $(10)_3$ dobija se da je

$$\lambda = 2k,\ k = 0, \pm1, \pm2, \ldots$$

Dakle, postoji beskonačno mnogo vrednosti λ_k. Za proizvoljno λ_k, iz preostalih uslova bice određene konstante A_k, B_k, C_k,, pa na osnovu principa superpozicije određuje se naponska funkcija f.

$$f = \sum_{k=0}^{\infty} f_k = \qquad (12)$$
$$= \sum_{k=0}^{\infty}\left(A_k r^{\lambda_k} + B_k r^{\lambda_k+2} + C_k r^{-\lambda_k} + D_k r^{-\lambda_k+2}\right)\cos\lambda_k\varphi$$

Na ovaj način dobija se traženo stanje napona.

Koristeći Hukov zakon, može se odrediti i polje pomeranja za posmatrani zadatak.

Ovaj model treba proveriti u praksi, pa, ako je potrebno, vršiti odgovarajuće korekcije. Tako naprimer, moglo bi se umesto krutog materijala, posmatrati čvrst ili sipki materijal. Zatim je moguće uzeti u obzir težinu tih delova, kao i dinamičke efekte usled kretanja i zatvaranja trake.

4. IMPACT OF CENTRIFUGAL FORCE ON THE STATE OF STRESS OCCURRING IN THE BELT

The advantage of pipeline conveyors is their capability of taking curves in horizontal plane. This feature is highly significant since it reduces the number of conveyors in the system, enables the bypassing of obstacles, hinders environmental pollution at transfer points etc.

It is known that when the belt enters into a horizontal curve centrifugal force is produced creating certain impacts. This paper analyzes the concurrent effect (additional stress) that occurs due to centrifugal force.

The centrifugal force, which apart from other (static) forces occurs in the curve, may be presented through the following expression:

$$m \cdot l \cdot \frac{v^2}{R}, \tag{13}$$

where
m – mass of belt with load per meter,
l – length of the belt in the curve,
R – curve radius.

The additional normal stress is:

$$\Delta\sigma = \frac{M_s}{I} y. \tag{14}$$

The state of stress is very complex. In this case, the component in the direction of the z - axis should be superposed to the direct state.

$$\{t_{ij}\} = \begin{Bmatrix} t_{rr} & t_{r\varphi} & 0 \\ t_{\varphi r} & t_{\varphi\varphi} & 0 \\ 0 & 0 & t_{zz} \end{Bmatrix}. \tag{15}$$

If it is established that P=t*h is the surface of the cross-section, by applying the Dalamberxs principle it will be:

$$\sum Y_i = dF - 2\sigma P \sin\frac{d\vartheta}{2} = 0 \cdot$$

$$\sin\frac{d\vartheta}{2} \approx \frac{d\vartheta}{2}$$

$$dF = \sigma P d\vartheta \text{ and } dF = adm = \frac{v^2}{R} dm = \frac{v^2}{R} \rho dV,$$

$$dV = P \cdot ds = P \cdot R d\vartheta,$$

$$\sigma = v^2 \rho \text{ where } \sigma = t_{zz}. \tag{16}$$

4. UTICAJ CENTRIFUGALNE SILE NA NAPONSKO STANJE U TRACI

Cevasti transporteri imaju tu prednost što mogu savladavati i krivine u horizontalnoj ravni. Ovo je veoma značajno, jer omogućuje smanjenje broja transportera u sistemu, zaobilaženje prepreka, smanjenje zagađenja okoline na presipnim mestima itd.

Pri nailasku trake na horizontalnu krivinu javlja se centrifugalna sila. Posmatra se dodatni efekat (dopunski napon) usled pojave centrifugalne sile.

Centrifugalna sila koja se, pored ostalih sila javlja u krivini, može se predstaviti sledećim izrazom:

$$m \cdot l \cdot \frac{v^2}{R}, \tag{13}$$

gde su:
m – masa trake sa teretom po metru,
l – dužina trake u krivini i
R – radijus krivine.

Dopunski normalni napon iznosi:

$$\Delta\sigma = \frac{M_s}{I} y. \tag{14}$$

Naponsko stanje je veoma složeno. U ovom slučaju ravnom stanju treba superponirati komponentu u pravcu z-ose.

$$\{t_{ij}\} = \begin{Bmatrix} t_{rr} & t_{r\varphi} & 0 \\ t_{\varphi r} & t_{\varphi\varphi} & 0 \\ 0 & 0 & t_{zz} \end{Bmatrix}. \tag{15}$$

Ako se pretpostavi da je P=t*h površina poprečnog preseka, primenom Dalamberovog principa biće:

$$\sum Y_i = dF - 2\sigma P \sin\frac{d\vartheta}{2} = 0 \cdot$$

$$\sin\frac{d\vartheta}{2} \approx \frac{d\vartheta}{2}$$

$$dF = \sigma P d\vartheta \text{ i } dF = adm = \frac{v^2}{R} dm = \frac{v^2}{R} \rho dV,$$

$$dV = P \cdot ds = P \cdot R d\vartheta,$$

$$\sigma = v^2 \rho \text{ gde je } \sigma = t_{zz}. \tag{16}$$

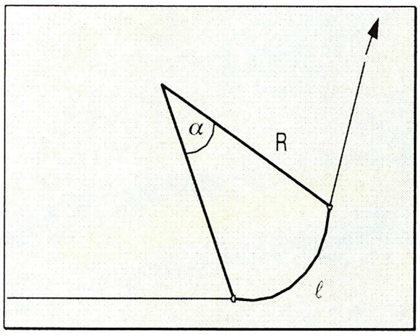

Figure 3a Chart of the curving belt

Slika 3a Šema trake u krivini

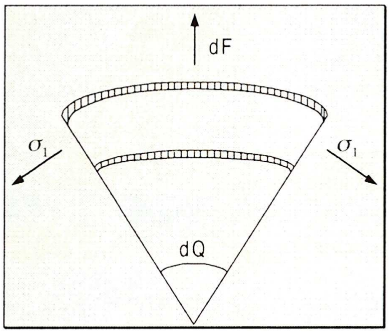

Figure 3b Chart of the curving belt

Slika 3b Šema trake u krivini

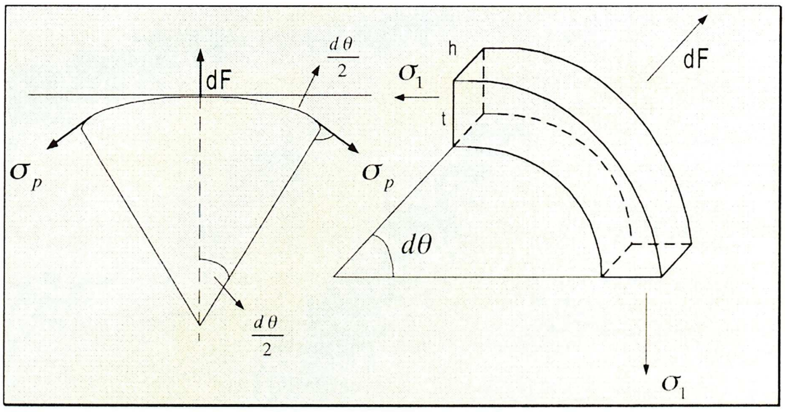

Figure 3c Chart of the curving belt

Slika 3c Šema trake u krivini

By analysing the former expression it may be deduced that the normal stress of this force does not depend on the shape and surface of the cross-section, but on the rate and density ρ. If started with given (limit) states of stress then the last formula may be used to determine the maximum rate of the pipeline belt with horizontal curves.

Analizom prethodnih izraza može se zaključiti da normalni napon od ove sile ne zavisi od oblika i površine poprečnog preseka, već od brzine kretanja i gustine ρ. Ako se pođe od zadatih (graničnih) napona, onda poslednji obrazac može poslužiti za određivanje maksimalne brzine kretanja cevaste trake sa horizontalnim krivinama.

5. CONCLUSION

Growing capabilities of pipeline belt conveyors for ore transportation impose a more serious approach to the issue of their use for simultaneous coal and ash transportation. The use of reversible pipeline belt conveyors will enable reduced energy consumption, economical employment of labour force, suppressing of ash disposal problems in the vicinity of coal-fired power plants. Besides, it will simplify the disposal and solidification of ash in previously prepared trench bunkers at open cast mines. To determine the parameters of pipeline belt conveyors it is necessary to establish the states of stress that occur in the belt during enclosing into pipe while entering into horizontal curve. In this way

5. ZAKLJUČAK

Sve veće mogućnosti primene cevastih transportera za transport mineralnih sirovina nametnule su potrebu ozbiljnijeg razmatranja njihovog korišćenja pri istovremenom transportu uglja i pepela. Primenom reverzibilnih cevastih transportera postigle bi se uštede u potrošnji energije, smanjilo bi se učešće radne snage, smanjio problem odlaganja pepela kod termoelektrana i pojednostavio proces odlaganja i očvršćavanja pepela u pripremljenim kasetama na površinskim kopovima. Kod određivanja parametara cevastih transportera neophodno je utvrditi napone u traci koji se javljaju prilikom njenog savijanja u cev i pri nailasku u horizontalnu krivinu. Na taj način je moguće definisati osnovne it is possible to define the basic belt parameters according to the conditions valid for particular routs.

parametre trake prema uslovima koji važe na određenoj trasi.

REFERENCES / LITERATURA

[1] Grujić M., Kuzmanović D., Ristović I., Šestak I.: SOME ASPECTS OF APPLICATION PIPE CONVEYORS IN MINING, Konferencie LOADO 2001, p.p. 257-260, High Tatras, 2001.

[2] Grujić M.: POSSIBILITIES OF AAPPLICATION OF REVERSIBLE BELT CONVEYORS FROM MINE TO STEAM POWER PLANT IN RETURN TRANSPORTATION OF THE ASHES, 2 Medz. konferencia Mineralurgija a environmentale tehnologie, p.p. 23-27, Herlany, 2001.

[3] Grujić, M.: TRANSPORT MINERALNIH SIROVINA KROZ ŽIVOTNU SREDINU (monografija), RGF, str. 112, Beograd, 1998.

[4] Grujić, M., Lončar, G.: ENVIRONMENTAL ADVANTAGES OF EXTERNAL CONTINUOUS COAL CONVEYANCE. International symposium 6th continuous surface mining, pp. 233-241 Freiberg, 2001.

[5] Lazić, M., Babović, M., Vukojičić P., Nemić D.: MODEL PLANIRANJA ODLAGANJA PEPELA U UNUTRAŠNJA ODLAGALIŠTA POVRŠINSKIH KOPOVA UGLJA. Zbornik radova MEP'01, str. 148-151, Vrdnik, 2001.

[6] Rekach, V.G.: MANUAL OF THE THEORY OF ELASTICITY, MIR Publischers, Moskow, 1979.

[7] Terzić, M., Nešić Lj.: PRIPREMA UNUTRAŠNJIH ODLAGALIŠTA NA POVRŠINSKIM KOPOVIMA UGLJA ZA DEPONOVANJE PEPELA IZ TERMOELEKTRANA, Zbornik savetovanja Rudarstvo i zaštita životne sredine, str. 113-116, Beograd, 1996