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SOME PROBLEMS OF HOISTING ROPE SELECTION AT THE DESIGN PROCEDURE OF INCLINED HOIST FOR HUGE TRUCKS TRANSPORTATION IN OPEN PIT MINING

Summary. The paper concerns a selected problem at the design procedure of inclined hoist for huge trucks transportation in open pits. The problem of proper assessment of hoist rope length and its further technical parameters plus decision of rope guidance occurs at the very beginning at the procedure. Author shows how to solve the problem considering comprehensively all aspects of it. He also indicates several new problems interesting from design point of view.

WYBRANE PROBLEMY DOBORU LIN NOŚNYCH W PROJEKTOWANIU WYCIĄGU POCHYŁEGO DO TRANSPORTU WIELKICH WOZÓW ODSTAWCZYCH W KOPALNIACH STOŻKOWYCH

Streszczenie. W artykule przedstawiono opis rozwiązania problemu, który pojawia się na wstępie w procedurze doboru lin urządzenia wyciągowego pochyłego. Mowa tu o obliczeniu długości lin nośnych wyciągu, decyzji o sposobie prowadzenia tych lin i problemów z tym związanych. Wszystkie ważniejsze aspekty tego zagadnienia zostały przedstawione. Wskazano na szereg dalszych, interesujących problemów związanych z procedurą projektową tego unikalnego systemu.

1. Introduction

Globalisation is a process that is being observed clearly nowadays. Rapid development of the Chinese industry for example causes greater need in steel market in the world. Prices of majority of metallic commodities raised drastically at the end of 2003 making considerable move in mining industry in many countries. Actually, there are the funds to develop many mining projects and to make a lot of improvements in mining methods and equipment involved. Some are in really great needs if funds are taken into account.

If open pit mining is concern the common practise is application of huge trucks to haul material won from pit. It is the only transports mean that fits specific requirements of this type of mining method. However, it possesses several great demerits in which expenditures are at the top. Huge prices of vehicles (*200* t truck cost roughly *2* million of US$, *300* t truck cost app. *3* million), the fact that half its way vehicle drives empty, significant fuel consumption (more than *100* l per *100* km averagely), the fact that truck consumes about *60*% of its energy to move itself, *40*% to move material transported etc. are the main points in this field. If we consider additionally that the whole machinery system that consists of few tens (sometimes more than *100*) of such vehicles (that produces necessity of possession of huge fuel reservoirs, one truck can accommodate a few thousands of *l* of fuel), large maintenance bay well equipped with personnel of high skill ness, frequent preventive maintenance needed and frequent long lasting repairs – all these are the reasons that any enhancement (cost cut) in this field is especially required.

One of the ways of improvement is the application of alternative way of transportation, i.e. employment of additional transport mean that is HAC preceded by crusher or application of inclined hoist to transport trucks to-and-fro the pit. The latter one is the newest proposition in this regard. However, it is a few years old.

Generally, this last proposition looks very well at the first glance. Nevertheless, more careful and insight analysis from operational point of view [1,2,3] raises several question and formulates tough conditions that are connected with such a system applied if it should be profitable in practice. The way of calculation of the system: *shovel-truck-inclined hoist* was presented in paper [2] and textbook [3].

The purpose of this paper is to present some interesting problems associated with the design procedure of such installation – calculation of rope length and it's way of guidance. Again, at the first glance, it looks that we are making typical design of hoist. The only exceptions are parameters of it – they are much greater than usually. The payload reaches several hundreds of tonnes in mass – fully loaded truck. But it is not true. The problem is much more complicated. This paper is a proof of such a statement.

2. Problem of hoisting rope length and associated predicaments

In the classical hoist installation design ordinary geometric dimensions of shaft plus location of deflecting sheaves and rope carrier (driving pulley) determine the rope length.

In the inclined hoist system the problem of rope length occurs at the very beginning of design procedure. The first step is connected with the selection of hoisting rope. It is commenced by calculation of the minimum metallic cross-section area S_0 from the well-known formula:

$$S_o = \frac{g\sum Q}{\eta(R_m / n) - \delta g \sum H}, \quad \text{mm}^2 \tag{2.1}$$

where:

g - the gravity acceleration, m/s^2,

ΣQ - total masses of load being carried (total mass of full truck plus mass of platform with suspension that carries it), kg,

η - efficiency factor of rope,

R_m - nominal tensile strength of steel wires, MPa,

n - statutory factor of safety,

$\delta g \Sigma H$ - total load of rope referred to *1* mm^2 of its cross-section, N/mm^2.

Looking at the above pattern we need to presume several parameters, namely:

- nominal tensile strength of steel wires R_m, MPa,
- statutory factor of safety n,
- *metallic density* of rope δ that is usually presumed as *0.0095* kg/m mm^2,
- efficiency factor of rope η.

The nominal tensile strength of steel wires R_m in conventional solutions is about *1800* to *1900* MPa. Taking into account that the total mass that will be carried can reach *500* t or even more, it is clear that we must take into consideration strength above *2000* MPa. Generally, it is not a problem.

The statutory factor of safety n for inclined hoist of such type is a problem. It should not be simply taken from mining regulations for inclined hoist because a lot of technical solutions at the system are unique and unverified. Moreover, some parameters are such high in value that are near corresponding limits. It means they should be treated with careful attention.

The efficiency factor of rope η used to be taken from corresponding mining regulations. However, ropes that could be employed in the system considered, again, have particularly high parameters and they are not applied commonly. Thus, the estimation of its efficiency could not be precise. Once more – it should be treated carefully.

The total masses that will be carried are the sum of mass of fully loaded truck (it can be up to *500* t) plus mass of the platform that will carry the vehicle. The mass of that platform depends on the technical solution realized by producer. We can assess that it should be *30*% of the total mass of truck, at least. Suspension applied in such a system can be conventional one.

Let us notice that both sums in formula (1) must comprise the influence of the angle of inclination (pit slope). Let us mark it by θ. Fig. 1 shows the idea of inclined hoist application and Fig. 2 presents the scheme of the system main geometric dimensions and acting forces in it.

Now is a time to consider the rope length that should be inserted in the discussed pattern. If rope in hoist is going directly down it is not a problem. However, rope in system considered is inclined, so it will have certain sag. The value of it will depend on several factors, among the other things, on the rope parameters – rope that is not yet chosen. Thus we have to assume a certain coefficient ζ that regards rope elongation due to rope sag. If we forecast that our rope will be guided, increment in rope length should not be high, say *5*%. This presumption must be verified in further part of the design procedure. If so, formula (1) will take shape:

$$S_0 = \frac{\left(Q_p + Q_d + Q_{plz}\right) g \sin\theta}{\eta \frac{R_m}{n} - \delta g \frac{H + H_1}{\sin\theta} \zeta} \tag{2.2}$$

where:

Q_p - full mass of empty truck, kg,

Q_d - maximum mass of material loaded on truck, kg,

Q_{plz} - mass of platform plus suspension, kg.

On the base of that we are selecting proper hoisting rope that fulfils determined requirements. It is obvious that for such huge values multirope system will be needed, *8* ropes or more. After selection we are in the possession of following rope parameters:

$$< \mathbf{k}, S_n, d, q, i >$$

that is: $\mathbf{k}$ specification of rope (its construction), S_n cross-section area of rope (metallic one), mm^2, d is rope diameter, mm, q is the mass of *1* m of rope, kg/m and i is the number of ropes applied.

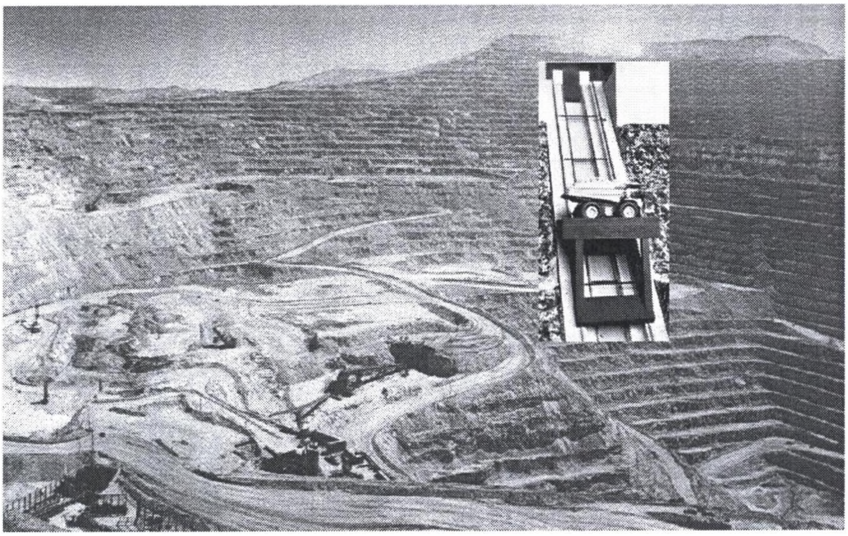

Fig. 1. Sketch of inclined hoist system in open pit mine
Rys. 1. Idea zastosowania wyciągu pochyłego w kopalni stożkowej

Now we have to verify our presumption concerning the real rope length.

3. Decision on the rope guidance

Here we have to consider the worst case – the empty platform is at the loading/unloading point down pit. In such a case is the lowest force stretching our hoisting ropes and obviously their deflection is of the highest value.

The force acting in a single rope is:

$$s = \frac{Q_{plz} g}{i} \sin\theta \text{, N.} \tag{3.1}$$

The length of rope chord:

$$c = (H+H_1)/\sin\theta \text{, m} \tag{3.2}$$

and it's horizontal projection:

$$l = (H+H_1)/\tan\theta \text{, m.} \tag{3.3}$$

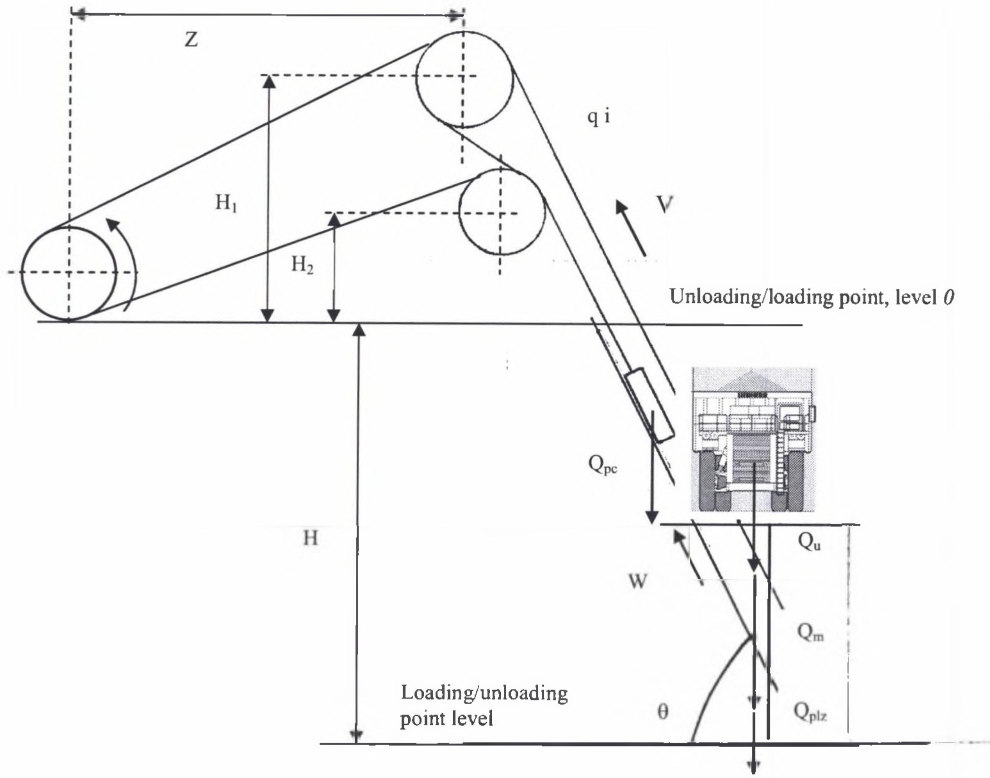

Fig. 2. Scheme of inclined hoist system, geometric dimensions and acting forces; key: *V* – velocity, *W* – resistance, Q_{pc} – mass of counterweight
Rys. 2. Schemat wyciągu pochyłego, wymiary geometryczne i siły; *V* – prędkość, *W* – siłą oporu, Q_{pc} – siła ciężkości przeciwwagi

Now we are able to estimate the length of rope supported in two points of different location, which the chord is under the angle θ (Gukiasashvili's pattern):

$$L_g = l + \frac{(H + H_1)^2}{2l} + \frac{q^2 l^3 g^2}{24 s^2 \cos\theta}, \text{ m} \tag{3.4}$$

that means our rope elongation is

$$[(L_g/c)-1]100, \%. \tag{3.5}$$

The maximum rope deflection (the vertical value) is (Chitari's formula):

$$f_{\max} = \frac{qgl^2}{8s\cos\theta}, \text{ m} \tag{3.6}$$

and the distance between the rope chord and the rope extreme point is:

$$m = f_{max} \cos\theta, \text{ m.} \tag{3.7}$$

Let us notice that the relationship between depth of wind x (vertical distance) and the distance m is:

$$m(x) = \frac{qg}{8s \tan\theta} x^2$$

and is the parabolic one (Fig. 3).

Conclusion: Practically, the value of m is high; the ropes must be guided (supported). This decision has influence on the rope length applied in the system.

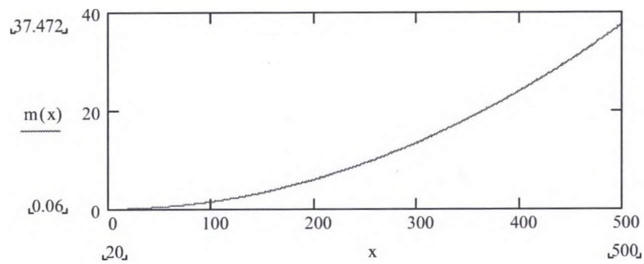

Fig. 3. Relation between depth of wind x and the distance among chord of rope and its extreme point
Rys. 3. Relacja pomiędzy głębokością ciągnienia a odległością pomiędzy cięciwą liny a jej najodleglejszym punktem

4. Determination of rope length

Having in mind the above relationships and knowing the distance between the rope chord and the plane of rope guiding rollers, say m_d, we can compute the level (vertical distance) of first rollers that should be applied. The first set of rollers must be fixed at:

$$x_1 = \sqrt{\frac{8m_d s}{qg}}, \text{ m} \tag{4.1}$$

Referring it to the level *0* we have:

$$x_2 = x_1 - H_1, \text{ m.} \tag{4.2}$$

Knowing that our system of ropes will not have identical behaviour always during operation we should build several roller sets nearby each other that will be ready to take first touch of ropes. Now is a time to calculate the rope length from deflecting sheaves[1)] or deflecting drum to the suspension.

We can distinguish three rope sectors:

- sector *I*: the rope length commencing from the point where rope leaves deflecting element to the point where rope touches guide roller set at the first time,
- sector *II*: the rope length from the first roller guide set the last one,
- sector *III*: the rope length from the last roller set to the suspension.

Calculation is as follows.

The rope length in sector *I* we can compute employing relationships shown in Fig. 4.

Here we have:

$$\tan\lambda = \frac{x_1}{\sqrt{\frac{x_1^2}{\sin^2\theta} - x_1^2 - \frac{m_d}{\sin\theta}}} \tag{4.3}$$

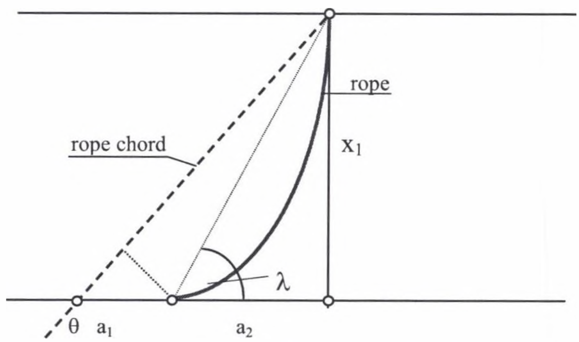

Fig. 4. Auxiliary sketch for rope length calculation at the first sector
Rys. 4. Rysunek pomocniczy dla obliczenia długości liny w przedziale pierwszym

$$l_I = x_1 / \tan\lambda \tag{4.4}$$

Thus the rope length in sector *I* we can assess as:

$$L_{gI} = l_I + \frac{x_1^2}{2l_I} + \frac{q^2 g^2 l_I^3}{24 s^2 \cos^2\lambda}, \text{ m.} \tag{4.5}$$

Let us now calculate the rope length in sector *III*.

Some of researches are of the opinion that if the difference between points of rope support is significant (that holds in our case), the rope sag shape can be described by a circle sector. If so, the rope length in sector *I* equals the rope length in sector *III*.

The rope length in sector *II* is approximately identical to corresponding its chord.

Therefore

$$L_{gII} = \frac{H + H_1 - 2x_1}{\sin\theta}, \text{ m.} \tag{4.6}$$

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[1] In the system of such type multirope solution is applied as a rule. Designers are of the opinion that is better to employ one deflecting element – drum, instead of *8*, *10* or *12* separate sheaves.

To be more precise, the rope length in sector *II* will be a little bit longer because our rope will have certain sag between particular roller sets. However, the sum of increment in rope length due to this fact will be rather low taking into account the rope rigidity (high rope diameter). Let us increase value of L_{gII} by *1%*.

Thus, the total rope length from deflecting element to the suspension we estimate as:

$$L_l = 2L_{gI} + 1.01L_{gII}, \text{ m.} \tag{4.7}$$

Now we are able to verify our presumption concerning the value of coefficient ζ.

The real value of this coefficient is:

$$\zeta_c = \frac{L_l \sin\theta}{H + H_1}. \tag{4.8}$$

5. Distance between guiding roller sets

If the allowable distance m_{dop} between the rope chord amongst roller sets and the extreme point of rope between these sets is determined by constructor, than the diagonal distance between roller sets should be:

$$d_{pr} = \sqrt{\frac{8m_{dop}s\tan^2\theta}{qg}\frac{1}{\sin\theta}}, \text{ m.} \tag{5.1}$$

6. Rope elongation because of sag depending on depth of wind

The total rope elongation because of the rope sag has been just assessed. Notice, that the rope elongation when rope is just leaving deflecting element is *0*. Thus, we should find the function that allows us to calculate rope length increment when depth of travelling platform increases. This function will be needed when we commence the assessment of the static moment on the main shaft of winder. It will be enough when we presume that this increment will be the linear one (total increment in the rope length is not so great). Therefore the formula:

$$\zeta(x) = \frac{\zeta_c}{H} x_c \quad (6.1)$$

will meet our requirements (Fig. 5).

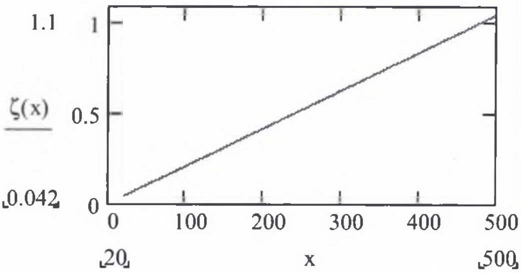

Fig. 5. Chart of function ζ(x) assuming $\zeta_c = 1.05$ and $H = 500$ m
Rys. 5. Wykres funkcji ζ(x) przyjmując $\zeta_c = 1.05$ i $H = 500$ m

Everything looks good at the first glance. Nevertheless, this function in connection with the formula describing the static moment on the winder shaft shows that the static moment will be determined by parabolic function with maximum at the point $x=H/4$. This is quite different pattern than that well known from conventional attitude.

7. Comments

This paper presents some particular problems connected with the design procedure of inclined hoist for transportation of huge hauling trucks. Here they are confined to the hoisting ropes of the system. The whole design process has a lot of interesting *puzzles* that are necessary to fit together and several challenges to reply in order to obtain the full information on main parameters, manners how to solve technically brand new problems.

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Recenzent: Prof. dr hab. inż. Adam Klich

Omówienie

Rok 2003 był zaskakujący na światowych rynkach rud metalicznych. Ceny większości metali wzrosły drastycznie, a firmy wydobywające minerały i firmy dostarczające metale dla odbiorców zanotowały znaczny wzrost zysków. Wszystko to spowodowało, że szereg kopalń na świecie zwiększa wydobycie, planowane są nowe przedsięwzięcia, rozważane jest wprowadzenie nowych rozwiązań zarówno operacyjnych (sposób sterowania systemami maszynowymi), technologicznych, jak i proponowane są nowe rozwiązania maszyn i innych urządzeń.

W kopalniach stożkowych, gdzie prowadzi się wydobycie rud metalicznych, odstawa wozami oponowymi jest dominująca. Tylko ten rodzaj środków odstawczych jest w stanie podołać bardzo ostrym wymaganiom, jakie tu stoją przed środkami transportowymi. Jednakże ten rodzaj transportu charakteryzuje wiele bardzo niekorzystnych wskaźników ekonomicznych. Mowa tu przede wszystkim o wysokiej cenie zakupu i utrzymania w ruchu wywrotek. To utrzymanie w ruchu obejmuje nie tylko wysokie koszty obsług profilaktycznych i częstych oraz długich napraw, dużego zużycia paliwa i konieczności posiadania wielkich zbiorników paliwowych, dużej i dobrze wyposażonej stacji obsługowej; to także niekorzystne parametry eksploatacyjne. Wóz tego typu zużywa ok. 60% swej energii na przemieszczanie samego siebie, 40% na transport materiału, połowę drogi wóz przejeżdża pusty. Wysoki jest także koszt personelu zarówno tego obsługującego wozy, jak i samych operatorów tych wywrotek. Wszystko to sprawia, że stale poszukuje się rozwiązań, których celem jest redukcja tych potężnych wydatków. Jak na razie propozycje są dwie: zastosowanie kruszarki w dole wyrobiska i odstawa materiału o zredukowanych wymiarach przenośnikiem „kanapkowym" z wyrobiska. Innym rozwiązaniem, nowszym, jest zastosowanie wyciągu pochyłego do transportu całych wozów; pełnych z wyrobiska, pustych na dół.

Autor prezentuje wybrany wycinek procedury projektowej – obliczenia związane z doborem, a przede wszystkim z właściwą oceną długości lin. Wskazuje na różnice pomiędzy klasycznym projektowaniem wyciągów a projektowaniem tego typu urządzenia pracującego pod nachyleniem. Sygnalizuje również szereg dalszych zagadnień, z jakimi trzeba się zmierzyć, projektując taki wyciąg na potrzeby górnictwa.