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STEEL WIRE ROPES AND TECHNICAL RISKS OF THEIR OPERATION

ČELIČNA UŽAD I RIZICI NJIHOVE PRIMENE

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Abstract: *Steel wire ropes we meet at many machines and devices. They represent an important construction element and rather strict requirement are laid upon them from the point of view of safe and reliable operation especially at the transport of people and material as well as in case of carrying and anchoring elements. According to the type of using from steel wire ropes is required a prescribed safety. Their value is affected by various factors that decrease the safety.*
Present European legislation requires for machines and their elements to carry out analysis of technical risk. These problems applied on steel ropes were solved at the Department of logistics and production systems. The influence of actual carrying capacity of steel ropes, the influence of acting dynamic forces and the influence of wear of wires of steel ropes on the safety was observed. All the mentioned influences decrease the safety of ropes and thereby also their reliability of operation.
On the basis of existing knowledge in case of steel ropes it is possible to say about the technical risk at decreasing the initial safety by 40 - 70 % in the dependence on the original value.

Key words: *steel wire rope, technical risk, safety, wear, dynamic stressing, service life, reliability*

Apstrakt: *Čelična užad predstavljaju sastavni deo mnogih mašina i uređaja. Oni su bitan konstrukcioni element i stoga moraju zadovoljiti stroge zahteve u pogledu bezbednosti i pouzdanosti rada, naročito kada je u pitanju transport radnika i materijala, kod nosećih elemenata i kod ankerisanja. Zavisno od njihove namene čelična užad moraju zadovoljiti unapred određen stepen bezbednosti. Njegova vrednost zavisi od različitih faktora koji utiču na smanjenje stepena bezbednosti.*
Po važećem evropskim propisima obavezno je vršenje analize tehničkih rizika za mašine i njihove elemente. Katedra za logistiku i proizvodne sisteme bavi se rešavanjem pomenute problematiike za oblast čeličnih užadi. Naime, proučava se kako na bezbednost čeličnih užadi utiču pojedini faktori kao što su; stvarna nosivost čeličnih užadi, vršne dinamičke sile i habanje. Svi navedeni faktori negativno utiču na bezbednost, pa samim tim, i na njihovu pouzdanost u radu.
Na osnovu raspoloživih saznanja moguće je proceniti tehnički rizik uzimajući u obzir da stepen bezbednosti čeličnih užadi opada za 40 - 70% u odnosu na početnu vrednost.

Ključne reči: *čelično uže, tehnički rizik, bezbednost, habanje, dinamičko naprezanje, radni vek, pouzdanost*

1. INTRODUCTION

Steel wire ropes are characterised by several variables and parameters. From the point of view of technical risk it is necessary to remind especially

1. UVOD

Nekoliko parametara i promenljivih vrednosti je karakteristiično za čeličnu užad. Da bi se utvrdila priroda tehničkog rizika i odredio njegov stepen, those, with which we will deal most at determining the risk and its evaluating. These are [1]:

- carrying capacity of steel rope,
- safety of steel rope,
- wear and corrosion of steel rope,
- static and dynamic stressing of steel rope.

potrebno je razmotriti sledeće parametre čeličnog užeta [1]:

- nosivost,
- bezbednost,
- habanje i koroziju,
- statičko i dinamičko naprezanje.

2. DEFINITION OF SELECTED PARAMETERS AND VARIABLES OF STEEL WIRE ROPES

The given definitions are taken from valid Slovak technical standards and technical literature.

2.1. Construction of steel wire rope

Under this term we understand the common arrangement of strands in the rope and wires in the strand. The construction of a rope can be expressed in two ways [1]:

a) In the STN by the number marking and illustration of the rope's cross-section, while the diameter of the rope is the complementary number before the standard's number. The first complementary digit after the standard's number depicts the nominal strength of wires out of which the rope is produced and the second complementary digit depicts the surface treatment of wires, direction and way of the rope's winding.
Example: 28 STN 024324.41.

b) The second way of the rope's depicting is more transparent. Before the parenthesis is given the number of rope's strands, in the parentheses is the number of wires in individual layers of the strand and after the parenthesis there is the type of insert, surface treatment of wires, nominal strength of wires and way and direction of winding the wires and the strands.
Example: 6(1+6+12) + v HO 1570 x P.

2.2. Carrying capacity of steel wire rope

The carrying capacity from the point of view of the user belongs to the most important parameters of steel ropes. According to the standard there are defined several types of carrying capacities [9]:

a) nominal carrying capacity of rope represents the sum of nominal carrying capacities of all the carrying wires of the rope. It is given in N or kN and for its calculation holds true the equation [9]

$$N_n = \sum_{i=1}^{n} n_i . S_i . \sigma_{ti} \text{ , [N].} \qquad (1)$$

2. DEFINISANJE IZABRANIH PARAMETARA I PROMENLJIVIH VREDNOSTI

Date definicije uzete su iz važećih slovačkih tehničkih standarda i savremene tehničke literature.

2.1. Konstrukcija čeličnog užeta

Pod ovim pojmom podrazumeva se uobičajeni raspored strukova u užetu i žica u struku. Konstrukcija užeta može se izraziti na dva načina [1]:

a) STN - brojem oznake i prikazom poprečnog preseka užeta, pri čemu prečnik užeta predstavlja dopunski broj koji stoji ispred broja koji označava struk. Prvi dopunski broj posle broja struka označava nominalnu čvrstoću žica od kojih se sastoji uže, dok drugi dopunski broj označava vrstu obloge žice, smer i način namotavanja.
Primer: 28 STN 024324.41.

b) Sledeći način obeležavanja užeta je daleko praktičniji i razumljiviji. Ispred zagrade dat je broj strukova u užetu, u zagradi dat je broj žica u svakom snopu struka i posle zagrade data je vrsta umetka, obloga žice, nominalna čvrstoća žica, smer i način namotavanja žica u struku.
Primer: 6(1+6+12) + v HO 1570 x P.

2.2. Nosivost čeličnog užeta

Iz perspektive korisnika nosivost je jedan od najvažnijih parametara čeličnih užadi. Prema standardu postoji nekiliko tipova [9]:

a) nominalna nosivost užeta predstavlja zbir nominalnih nosivosti svih nosećih žica u datom užetu. Izražena je u N ili kN, a za obračun primenjuje se jednačina [9]:

$$N_n = \sum_{i=1}^{n} n_i . S_i . \sigma_{ti} \text{ , [N].} \qquad (1)$$

where:
N_n - nominal carrying capacity in N,
n_i - number of wires of the same diameter,
S_i - nominal cross-section of wires of the same diameter,
σ_{ti} - nominal strength of wires of the corresponding diameter in MPa.

The nominal carrying capacity of ropes of the same construction depends on the nominal strength of wires that were used for its production. The nominal carrying capacity represents the minimum carrying capacity of the rope [1].

b) The calculated carrying capacity of the rope is the sum of actual carrying capacities of carrying wires of the rope, their value can be acquired by tensile tests of individual wires. The calculated rope's carrying capacity is higher when comparing with the nominal carrying capacity, while it can be different only in certain limits [1].

c) The inclusive carrying capacity of the rope is defined as the calculated carrying capacity of the steel rope, reduced by carrying capacities of wires that at tests did not meet requirements of the STN 024301.1 [9].

d) The average carrying capacity of the rope replaces the inclusive carrying capacity at ropes produced according to he STN 024301.2 [8]. The average carrying capacity of the rope can be acquired as the sum of the average carrying capacity of a certain smaller number of carrying wires. In this carrying capacity again are not included wires that did not meet requirements of the STN [8].

e) The actual carrying capacity of the rope is found out by tearing a sample of steel wire rope, it is the largest achieved force at tensile test of a sample of the whole rope. This is always lower than the nominal carrying capacity. Its percentage values from the nominal strength are given in Table 1 [1].

gde je:
N_n - nominalna nosivost izražena u N,
n_i - broj žica istog prečnika,
S_i - nominalni poprečni presek žica istog prečnika i
σ_{ti} - nominalna čvrstoća žica odgovarajućeg prečnika izražena u MPa.

Nominalna nosivost užadi iste konstrukcije zavisi od nominalne čvrstoće žica koje su korišćene za njihovu izradu. Nominalna nosivost predstavlja minimalnu nosivost [1].

b) Obračunata nosivost užeta je zbir stvarne nosivosti nosećih žica datog užeta. Ova vrednost može se dobiti ispitivanjem na istezanje svake pojedinačne žice. Obračunata nosivost užeta veća je od nominalne nosivosti, ali može se razlikovati samo do određene granice [1].

c) Ukupna nosivost užeta može se definisati kao obračunata nosivost čeličnog užeta, umanjena za pojedinačne nosivosti žica koje prilikom ispitivanja nisu zadovoljile STN 024301.1 [9].

d) Prosečna nosivost užeta zamenjuje ukupnu nosivost kod užadi koja su proizvedena u skladu STN 024301.2 [8]. Prosečna nosivost užeta može se dobiti kao zbir prosečne nosivosti određenog manjeg broja nosećih žica. U ovu nosivost, takođe, nisu uključene žice koje nisu zadovoljile STN [8].

e) Stvarna nosivost čeličnog užeta može se ustanoviti kidanjem jednog uzorka, što predstavlja najveću silu koja se može postići u okviru ispitivanja na istezanje. Ova vrednost uvek je manja od nominalne nosivosti. Procentualne vrednosti u odnosu na nominalnu vrednost date su u tabeli [1].

Table 1 Actual carrying capacity of steel wire ropes
Tabela 1 Stvarna nosivost čeličnog užeta

Quality	Construction of steel wire rope	% of nominal carrying capacity
V	- one-strand rope	80,0
	- double wound ropes with one layer of ropes in strands	90,0
	- double wound ropes with two layers of ropes in strands	85,0
	- double wound ropes with three layers of ropes in strands	82,0
	- all parallel constructions without regarding number of wires in strands	75,0
N	- ropes with number of wires to 222 except parallel constructions	80,0
	- ropes with greater number of wires as 222 and all parallel constructions	75,0

The actual carrying capacity of ropes is affected by more factors, the decisive one is the construction of the steel rope.

Na stvarnu nosivost užadi utiču razni faktori, ali je, pri tom, odlučujući faktor konstrukcija čeličnog užeta.

2.3. Safety of steel wire rope

At the calculation we come out from the nominal or inclusive carrying capacity of steel rope that occurs in the numerator of the equation for its calculation. In the denominator is the maximum static load of the rope [1].

$$s = \frac{N}{F_{\max}}, \qquad (2)$$

were:
s - safety of rope (non-dimensional parameter),
N - nominal or inclusive carrying capacity of rope in N,
F_{max} - maximum static load,

The value of the safety is given by standards and regulations, depends on type of the device on which the rope is used, or on its purpose. In Table 2 there are given ranges of the safety for various types of ropes valid in various European states [1].

2.3. Stepen bezbednosti čeličnog užeta

Prilikom obračuna polazi se od nominalne ili ukupne nosivosti čeličnog užeta koja se javlja u brojitelju jednačine za obračun. U imenitelju jednačine nalazi se maksimalno statičko opterećenje [1].

$$s = \frac{N}{F_{\max}}, \qquad (2)$$

gde je:
s – stepen bezbednosti užeta (nedimenzionisan parametar),
N – nominalna ili ukupna nosivost užeta izražena u N,
F_{max} – maksimalno statičko opterećenje,

Vrednost kojom se označava stepen bezbednosti izražena je kroz standarde i pravila, zavisi od vrste uređaja u okviru koga je uže upotrebljeno, ili od njegove namene. U tabeli 2 dat je bezbednosni limit za različite tipove užadi koji je trenutno na snazi u nekoliko evropskih zemalja [1].

Table 2. Safety of steel ropes
Tabela 2 Bezbedonosni limit čeličnih užadi

Type of rope	Safety
- hoisting	6-9
- balancing	5-7
- guiding and reflex	5-7
- carrying ropes of rope-ways	3,5-4
- tractive ropes of rope-ways	5-6
- lift	8-16
- crane	3-8,5
- anchoring	3,5-5
- ropes of ski-lifts	4-5

2.4. Wear and corrosion of steel wire rope

The wear and corrosion of wires of a steel rope decrease the metallic cross-section of the rope as well as its carrying capacity. That is why the standards and regulations limit the value of wear. In the Slovak Republic for hoisting ropes the allowed maximum decrease of the metallic cross-section id 20 %.

The cause of wear of wires of steel ropes is their common contact with the surface of the groove of pulleys and sheaves as well as at winding the rope on the drum in various layers the common contact

2.4. Habanje i korozija čelične užadi

Habanjem i korozijom žica čeličnog užeta, smanjuje se poprečni presek metalnog dela užeta kao i njegova nosivost. Iz tog razloga standardi i pravila ograničavaju stepen habanja. U Slovačkoj Republici za izvoznu užad maksimalno dozvoljeno smanjenje poprečnog preseka je 20%.

Uzrok habanja žica čeličnog užeta je njihov kontinuirani kontakt sa žljebom koturače i kotura, kao i zbog toga što je na bubnju uže of the rope's surface between lower and upper layers.

The corrosion of steel ropes is a topical degradation process at their work in wet the environment. Both factors, the wear and the corrosion, unfavourably affect the reliability and safety of steel ropes [1].

2.5. Stressing of steel wire ropes

Although the safety of steel ropes is calculated from their load by static forces, acting further types of stressing is taken into consideration by increased safety coefficient. On the rope during its movement on an arbitrary device act three types of forces:

F_{st} - static force being formed by acting the weight on the rope,
F_{dyn} - dynamic force, being the result of uneven movement of steel rope and its load,
F_{bp} - bending force being spent on bending ropes at its passing through pulleys and sheaves or at its winding on the drum.

For the calculation of individual types of forces hold true equations [1]:

$$F_{st} = G_{tot}\, g,\ [N], \quad (3)$$

$$F_{dyn} = 1{,}5\ G_{tot.}a,\ [N], \quad (4)$$

$$F_{bp} = \frac{E\delta_d .S}{D},\ [N], \quad (5)$$

where:
G_{tot} - weight of all the loads suspended on the rope including the weight of the rope in m,
E - modulus of elasticity of the steel rope in $N.m^{-2}$,
δ_p - diameter of surface wires of steel rope in m,
S - metallic cross-section of the steel rope in m^2,
D - diameter of pulley, sheave or drum through which the rope in bent in m,
a - acceleration at the acceleration period in $m.s^{-2}$,
g - gravitational acceleration 9.81 $m.s^{-2}$.

The maximum force should not be greater than 20 - 25 % of the carrying capacity of the steel rope [1].

3. TECHNICAL RISKS OF OPERATION OF STEEL WIRE ROPES

The legislation of states of the European Union considers the safety of machine devices and the safety of work as one of its most important areas. The directive of the Council of Europe

namotano u nekoliko slojeva i dolazi do stalnog kontakta između donjih i gornjih slojeva.

Korozija čelične užadi je proces koji je posebno izražen u uslovima povećane vlažnosti. Oba pomenuta faktora, habanje i korozija, nepovoljno utiču na pouzdanost i bezbednost rada čelične užadi [1].

2.5. Naprezanje čelične užadi

Iako se bezbednost čelične užadi izračunava na osnovu opterećenja prouzrokovanog statičkim silama, drugi vršni vidovi naprezanja su uzeti u obzir za uvećani koeficijent bezbednosti. Naime, u toku kretanja, na uže bilo kog uređaja deluju tri vrste sila, i to:

F_{st} – statička sila koja nastaje delovanjem tereta na uže,
F_{dyn} – dinamička sila koja je rezultat neravnomernog kretanja čeličnog užeta i tereta,
F_{bp} – sila savijanja koja se javlja prilikom prolaska užadi kroz koturače i koturove ili prilikom namotavanja na bubanj.

Za obražun pojedinačnih vrsta sila koriste se sledeće jednačine [1]:

$$F_{st} = G_{tot}\, g,\ [N], \quad (3)$$

$$F_{dyn} = 1{,}5\ G_{tot.}a,\ [N], \quad (4)$$

$$F_{bp} = \frac{E\delta_d .S}{D},\ [N], \quad (5)$$

gde je:
G_{tot} - težina svih tereta obešenih o uže uključujući i težinu samog užeta, m,
E - modul elastičnosti čeličnog užeta, $N.m^{-2}$,
δ_p – prečnik površinskih žica u čeličnom užetu, m,
S – poprečni presek metalnog dela užeta, m^2,
D – prečnik koturače, kotura ili bubnja preko koga je savijeno uže, m,
a - ubrzanje tokom vremena ubrzanja, $m.s^{-2}$ i
g - gravitaciono ubrzanje 9.81 $m.s^{-2}$.

Maksimalna sila mora biti veća 20 - 25 % od ukupne nosivosti čeličnog užeta [1].

3. TEHNIČKI RIZIK PRI RADU ČELIČNE UŽADI

Zakonodavstvo Evropske Unije smatra da bezbednost rada mašina i uređaja i bezbednost na radu spada u jednu od najznačajnijih oblasti njenog delovanja. Direktivom Saveta Evrope 89/392/EOVS nalaže se sprovođenje analiza rizika i primena

89/392/EOVS gives the duty to carry out the analysis of risk and apply methods of the risk control. At the same time it comes out from the assumption of knowing the mechanism of forming the negative phenomena in the system man - machine - environment, that is judging the safety of the system as well as the possibility of endangering [3].

3.1. Risk and its types

The risk is defined as the combination of probability of forming negative phenomenon and its consequence [3]. In everyday operation we meet the acceptable and the residual risk.

The *acceptable risk* is such a risk which at the operation of technical systems in production processes and working activities the interested are willing to bear under the assumption that there are taken into the consideration all the operational and technical conditions. The existing experience and technical knowledge show that the frequency of the applicable risk is in limits from 10^{-5} to 10^{-7} [3].

The *residual risk* is used in case of technical devices. The technical devices are not constructed on the 100 % safety of the operation. That is why the producer in the directions for service provides the user with the information on the probability of forming the negative phenomenon and its consequence, i.e. on the residual risk. At the same time there are stated measures that are to be kept in order to decrease consequences of the residual risk [3].

3.2. Risk factors and risk control

As the risk factors are considered various technical or human parameters of objects and activities influencing the risk. Their expressing can by done by a concrete number value, these are so called measurable parameters. At steel ropes we can range among them for example the:

- carrying capacity of steel rope (N),
- weight of suspended load (kg),
- velocity of movement ($m.s^{-1}$),
- D/d ratio,
- number of working cycles (n/time datum).

The second group of parameters is created measurable parameters having an important influence on the probability and consequences of forming negative phenomena. In case of steel ropes we can range among them e.g. the:

- qualification of the operating personnel,

metoda kontrola rizika. Istovremeno, polazeći od pretpostavke da sprega čovek – mašina – okolina prouzrokuje negativne efekte zna se da procena stepena bezbednosti podrazumeva i procenu mogućnosti ugrožavanja okoline [3].

3.1. Vrste rizika

Rizik se definiše kao verovatnoća nastajanja negativne pojave i njene posledice [3]. U svakodnevnom radu nailazimo na prihvatljivi i propratni rizik.

Prihvatljiv rizik je rizik koji su zainteresovane strane voljne da snose u toku rada određenog tehničkog sistema u okviru proizvodnog procesa, a prilikom obavljanja radnih aktivnosti, pod pretpostavkom da su uzeti u obzir svi radni i tehnički uslovi. Dosadašnje iskustvo i tehnička saznanja pokazuju da se učestalost prihvatljivog rizika kreće u granicama od 10^{-5} do 10^{-7} [3].

Propratni rizik je pojam koji se koristi za tehničke uređaje. Konstrukcija tehničkih uređaja ne pruža 100%-tnu bezbednost rada. Zbog toga proizvođač opreme u uputstvu za upotrebu navodi verovatnoću nastanka negativnih pojava i njene posledice, tj. obezbeđuje korisniku informaciju o propratnom riziku. Istovremeno se navode mere koje trebe primenjivati, kako bi se posledice propratnog rizika umanjile [3].

3.2. Faktori rizika i kontrola rizika

Pod faktorima rizika podrazumevaju se razni tehnički i ljudski parametri koji se odnose na određene objekte i aktivnosti koji utiču na rizik. Oni se mogu izraziti konkretnim brojčanim vrednostima, to su takozvani merljivi parametri. Kod čelične užadi razlikujemo na primer:

- nosivost čeličnog užeta (N),
- težinu obešenog tereta (kg),
- brzinu kretanja ($m.s^{-1}$),
- D/d odnos i
- broj radnih ciklusa (n/vreme podatak).

Druga grupa parametara značajno utiče na vreovatnoću i posledice nastanka negativnih pojava. Kada su u pitanju čelična užad razlikujemo parametre, kao što su, na primer:

- obučenost kadra,

- technical state of the device on which the rope works,
- quality of control of the steel rope,
- discipline of other persons.

For the risk control it is necessary to know the importance of certain basic terms, by which are named the procedures in the risk control activities complex. Such procedures are [3].

The risk analysis, by which the judged system is determined and the endangerment and risk is found out.

The risk verification represents the judgement of the system safety and adopting the corresponding measures.

The risk control includes procedures evaluating the risk as the measure of endangerment during the carrying out the analysed activity, namely the probability and consequence of the negative phenomenon and the possibility of their mutual combination.

3.3. Causal dependence of forming the damage of steel wire rope

The application of the risk control method requires knowing the mechanism of forming the negative phenomenon within the scope of the system man - machine - environment. By the analysis of negative phenomena on devices using steel ropes was confirmed that there is a casual dependence of forming the damage, accident or injury. In Table 3 [2] there is given the scheme of the casual dependence for some operation conditions of the steel rope's work.

- stanje tehničke ispravnosti uređaja koji koriste čeličnu užad,
- kvalitet kontrole čeličnog užeta i
- disciplina osoblja.

Za kontrolu rizika neophodno je uvideti značaj određenih osnovnih propisa kojima su definisane procedure u okviru delatnosti za kontrolu rizika. Razlikuju se sledeće procedure [3].

Analiza rizika, kojom se definiše analizirani sistem, određuje se stepen ugroženosti i rizici.

Verifikacija rizika predstavlja procenu bezbednosti sistema i usvajanje odgovarajućih mera.

Kontrola rizika podrazumeva procedure kojima se procenjuje rizik kao kriterijm ugrožavanja u procesu obavljanja analizirane aktivnosti. Naime procenjuje se verovatnoća nastajanja negativnih pojava, posledice ovih pojava i mogućnost njihovog međusobnog kombinovanja.

3.3. Štetne pojave kod čeličnih užadi i uzročna zavisnost

Primena metode za kontrolu rizika zahteva poznavanje mehanizama koji dovode do stvaranja negativnih pojava u okviru sprege čovek – mašine – okolina. Analizom negativnih pojava koje se javljaju na uređajima sa čeličnom užadi potvrđeno je da postoji uzročna zavisnost između štetnih pojava, nesrećnih slučajeva i povreda. U tabeli 3 [2] prikazana je šema uzročne zavisnosti za pojedine uslove rada čelične užadi.

Table 3 Casual dependence of negative phenomena during the operation of steel wire rope
Tabela 3 Šema uzročne zavisnosti za pojedine uslove rada čelične užadi

danger	endangerment	initiation	damage	harm
operation conditions	corrosion	environment-humidity	damaged wires in the rope	breaking the rope, fall of the weight, possible injury, damage of things under the weight
	wear	contact rope - pulley, their various material	decreasing the cross-section, disruptions of wires	
	dynamic stressing	vibration of rope, changes of velocity	decreasing the safety	

Knowing the negative phenomena and their influence on steel ropes in the operation enables the user of the rope to suggest such measures that prevent forming the negative phenomena or break the development of the casual dependence. The most suitable is to achieve such a state already during first steps of the casual dependence. For the given possibilities of endangerment in Table 1 the user must safeguard [2]:

Poznavanje negativnih pojava i uticaja koji imaju na čeličnu užad u toku rada omogućava korisniku da predloži mere za prevenciju njihovog nastanka ili da zaustavi dalji razvoj uzročne zavisnosti. Najpogodnije je da se pomenuti uslovi obezbede već u samom nastanku uzročne zavisnosti. Za potencijalne oblike ugrožavanja koje su prikazane u tabeli 1 korisnik treba da obezbedi [2]:

- excluding the humidity or forming the construction conditions for preventing the corrosion creation,
- solving the contact between the rope and the pulley by using a suitable material in the groove or decreasing the pressure between the rope and the pulley,
- removing the vibration of the rope and possibilities of sudden changes of the velocity of movement of the weight.

3.4. *Factors influencing technical risks of operation of steel wire ropes*

Coming out from the analysis of causes of technical risks of steel wire ropes that decrease the reliability and safety of their operation, of the most importance influencing the technical risk are 3 factors:

- actual carrying capacity of the rope,
- wear and corrosion of the steel rope,
- dynamic stressing of the steel rope.

3.4.1. The actual carrying capacity of the rope was defined in the 2.2 part. Its relation to the nominal carrying capacity is represented by the so called coefficient of the carrying capacity given by he equation:

$$k_a = \frac{N_a}{N_n} \qquad (7)$$

where:
N_a - actual carrying capacity in N or kN,
N_n - nominal carrying capacity in N or kN.

On the basis of experimental determining the actual carrying capacity of steel ropes of various constructions, the value of the k_a is from 0.72 to 0.95 [6], while the rope's safety calculated from the nominal carrying capacity is decreased.

3.4.2. The wear and corrosion of the steel rope decrease the metallic cross-section as well as the carrying capacity of the rope [4]. There are determined maximum values of loss of the metallic cross-section as well as the carrying capacity, in the Slovak Republic for the hoisting ropes the maximum allowed loss of the metallic cross-section is 20 %. By the wear and corrosion the calculated safety is henceforth decreased, this fact is expressed by the coefficient of wear k_w [3], for determining the operation risk of the steel rope was considered in limits 0.8 – 1.

- zaštitu od vlage ili odgovarajuće uslove koji sprečavaju nastanak korozije,
- rešavanje problema kontakta između užeta i koturače oblaganjem žljeba odgovarajućim materijalima ili smanjenjem pritiska između užeta i koturače i
- onemogućavanje vibracija užeta i naglih promena brzine kretanja tereta.

3.4. *Faktori koji utiču na pojavu tehničkih rizika u procesu upotrebe čelične užadi*

Na osnovu analize uzroka tehničkih rizika prilikom korišćenja čelične užadi koji utiču na smanjenje pouzdanost i bezbednost rada došlo se do zaključka da na tehnički rizik najviše utiču sledeća 3 faktora:

- stvarna nosivost čeličnog užeta,
- habanje i korozija čeličnog užeta i
- dinamičko naprezanje čeličnog užeta.

3.4.1. Stvarna nosivost čeličnog užeta definisana je u odeljku 2.2. Odnos stvarne i nominalne nosivosti predstavljen je takozvanim koeficijentom nosivosti koji je iskazan jednačinom:

$$k_a = \frac{N_a}{N_n}, \qquad (7)$$

gde je:
N_a – stvarna nosivost izražena u N ili kN i
N_n – nominalna nosivost izražena u N ili kN.

Stvarna nosivost čelične užadi na nekoliko objekata utvrđena je eksperimentalno i njena vrednost k_a kreće se od 0.72 do 0.95 [6], dok se bezbednost užeta izračunava na osnovu umanjene nominalne nosivosti.

3.4.2. Habanje i korozija čeličnog užeta umanjuju poprečni presek metalnog dela užeta i njegovu nosivosti. [4]. Utvrđene su maksimalne vrednosti za gubitak poprečnog preseka metalnog dela i za nosivost. U Slovačkoj Republici za izvoznu užad maksimalno dozvoljeni gubitak u poprečnom preseku metalnog dela iznosi 20%. Za habanje i koroziju izračunati stepen sigurnosti je umanjen, pomenuta činjenica izražena je koeficijentom habanja k_w [3], a za određivanje rizika pri radu čelične užadi razmatra se u okviru granica 0.8 do 1.

3.4.3 The dynamic stressing of the steel rope can be evaluated by the coefficient of dynamic stressing which is calculated from the equation [5]:

$$k_d = \frac{F_{stmax} + \Delta F_{max}}{F_{stmax}} \qquad (8)$$

where:

F_{stmax} - maximum static force acting on the steel rope in N,

ΔF_{max} - maximum amplitude from the maximum actual static force in N.

The value of forces needed to the calculation was acquired by experimental measurements on hoisting devices at Košice and Rud any for various regimes of movement of the rope, its values are given in Table 4 [5].

3.4.3. Dinamičko naprezanje čeličnog užeta može se definisati pomoću koeficijenta dinamičkog naprezanja koji se obračunava na osnovu formule [5]:

$$k_d = \frac{F_{stmax} + \Delta F_{max}}{F_{stmax}}, \qquad (8)$$

gde je:

F_{stmax} – maksimalna statička sila koja deluje na čelično uže, izraženo u N i

ΔF_{max} – maksimalno odsupanje od stvarne statičke sile, izraženo u N.

Vrednost sila za potrebe obračuna dobijene su vršenjem eksperimentalnih merenja na izvoznom postrojenju u Košicama i Rudnjanima i to za razne režime kretanja užeta. Pomenute vrednosti prikazane su u tabeli 4 [5].

Table 4 Coefficient of dynamic stressing of the rope
Tabela 4 Koeficijent dinamičkih sila za užad

Hoisting device	Direction of movement	regime of movement of the TV	k_d
Shaft Východ Košice	down	accelerating period	1,23
		stopping period	2,16
		sudden breaking	3,86
	up	accelerating period	1,22
		even stopping period	1,77
		sudden breaking	3,59
Shaft Poráč Rud any	down	accelerating period	1,25
		stopping period	1,45
	up	accelerating period	1,24
		stopping period	1,46
	TV at rest	caging cars	1,06
		uncaging cars	1,08

TV - transport vessel

The value of the coefficient of dynamic stressing of steel rope is in rather wide limits (1.06 - 3.86). It depends especially on the change of the velocity of movement of rope, on the frequency of the longitudinal vibration of the rope owing to change of loading and on the direction of movement. From the point of view of technical risk in the operation of steel ropes the biggest danger is in sudden stopping the movement of the steel rope.

Vrednost koeficijenta dinamičkog naprezanja čeličnog užeta kreće se u relativno širokom opsegu (1.06 - 3.86). Pomenuta vrednost posebno zavisi od promene brzine kretanja užeta, od učestalosti uzdužnih vibracija užeta usled promena koje nastaju pri utovaru i od smera kretanja. Sa tačke gledišta potencijalnog tehničkog rizika najveća opasnost nastaje prilikom naglog zaustavljanja kretanje čeličnog užeta.

4. ACTUAL SAFETY OF STEEL ROPES

Described risk factors decrease the safety and reliability of operation of steel ropes. On the basis of regarding these three decisive risk factors the actual safety of a rope in operation will be:

$$b_a = \frac{b.k_a.k_o}{k_d} \qquad (9)$$

4. STVARNA BEZBEDNOST ČELIČNOG UŽETA

Opisani faktori rizika umanjuju bezbednost i pouzdanost rada sa čeličnom užadi. Analizirajući ova tri presudna faktora može se ustanoviti da je stvarna bezbednost čeličnog užeta u radu:

$$b_a = \frac{b.k_a.k_o}{k_d}. \qquad (9)$$

In this equation are parameters from previous formulas. The value of actual safety for various combinations and values of actual carrying capacity, wear and corrosion, as well as dynamic stressing are given in Table 5. The calculated safety is related to the nominal carrying capacity of steel ropes.

U ovoj jednačini javljaju se parametri iz prethodnih formula. Vrednost stvarnog stepena bezbednosti za nekoliko kombinacija i vrednosti stvarne nosivosti, habanja i korozije, kao i dinamičkog naprezanja date su u tabeli 5. Izračunati stepen bezbednosti odnosi se na nominalnu nosivost čeličnog užeta.

Table 5. Change of actual safety of rope during the operation by influenced by risk factors

Influencing factors		Calculated safety					
		2	4	6	8	10	12
actual carrying capacity k_a	0,70	1,4	2,8	4,2	5,6	7,0	8,4
	0,75	1,5	3,0	4,5	6,0	7,5	9,0
	0,80	1,6	3,2	4,8	6,4	8,0	9,6
	0,85	1,7	3,4	5,1	6,8	8,5	10,2
	0,90	1,8	3,6	5,4	7,2	9,0	10,8
	0,95	1,9	3,8	5,7	7,6	9,5	11,4
Wear at $k_a = 0,70$ $k_d = 3,86$	0,80	0,29	0,58	0,87	1,16	1,45	1,74
	0,85	0,31	0,62	0,93	1,24	1,55	1,86
	0,90	0,33	0,66	0,99	1,32	1,65	1,98
	0,95	0,35	0,70	1,05	1,40	1,75	2,10
coefficient of dynamic stressing (k_d) at $k_a = 0,70$ $k_d = 0,80$	1,22	0,92	1,84	2,76	3,68	4,60	5,52
	1,50	0,75	1,50	2,25	3,00	3,75	4,50
	2,0	0,56	1,12	1,68	2,24	2,80	3,36
	2,5	0,45	0,90	1,35	1,80	2,25	2,70
	3,0	0,37	0,74	1,11	1,48	1,85	2,22
	3,5	0,32	0,64	0,96	1,28	1,60	1,92
	3,86	0,29	0,58	0,87	1,16	1,35	1,74

In the Table given actual safety confirms tat its decreasing occurs at cumulating risk factors. Out of them as the most important is to be considered the acting of dynamic forces, the biggest values of them occur, however, randomly.

Stvarni stepen bezbednosti prikazan u tabeli potvrđuje da sa njegovim opadanjem rastu i faktori rizika. Vršne dinamičke sile treba smatrati najznačajnijim faktorom rizika, iako se najveće vrednosti ovih sila javljaju samo povremeno.

5. CONCLUSIONS

Coming out from the existing knowledge and especially from the value of actual safety of steel ropes calculated according to equation (9) that considers decisive risk factors it is possible to do the following conclusions:

- the value of decrease of calculated actual safety at the operation risk of steel rope depends on the value of initial safety,
- the most dangerous factor increasing the technical risk of operation of steel ropes is their stressing by dynamic forces,
- the actual carrying capacity and wear with the corrosion affect the technical risk of operation of ropes practically by the same measure and their acting especially at higher initial safety (4 and more) is practically negligible,
- for ropes with low initial safety (2 - 5) already the decrease of safety by 30 - 50 % represents the technical risk,

5 ZAKLJUČCI

Na osnovu postojećih saznanja, a naročito na osnovu vrednosti stvarnog stepena bezbednosti, koji je za čeličnu užad izračunat na osnovu jednačine (9) za presudne faktore rizika, moguće je izvesti sledeće zaključke:

- smanjenje stvarnog stepena bezbednosti rada čelične užadi zavisi od početnog stepena bezbednosti,
- faktor koji maksimalno povećava stepen tehničkog rizika rada čelične užadi je naprezanje usled dinamičkih sila,
- stvarna nosivost i habanje sa korozijom utiču na stepen tehničkog rizika rada užadi, praktično, u istoj meri, dok je njihovo delovanje kod početnog stepena bezbednosti praktično zanemarljivo, naročito ako je početna bezbednost povećana (4 i više),
- za užad sa manjim početnim stepenom bezbednosti (2 - 5) samo smanjenje stepena

- for the rope with higher initial safety (6 and more) its decrease by 50 - 80 % is to be considered as technical risk.

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bezbednosti od 30 - 50 % predstavlja tehnički ruzik,
- za užad sa većim stepenom početne bezbednosti (6 i više) tek smanjenje od 50 - 80 % predstavlja tehnički rizik.

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