ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 1986

Seria: GORNICTWO z. 143 Nr kol. 883

1st International Conference - Reliability and Durability of Machines and Machinery Systems in Mining
1986 JUNE 16-18 SZCZYRK, POLAND

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UPPER ESTIMATION OF THE SURVIVAL FUNCTION FOR HOISTING ROPES

Summary. In the paper the upper estimation and way of its obtaining for survival function for hoisting ropes were shown. The estimation has been got analysinig physical processes of ropes and considering the process of increment of rope wires breaks. Relations between the obtained estimation and possible runs of wearing process from increment of weakness of rope stand point and mathematical approach to modeling of wearing process were also analysed.

1. INTRODUKCTION

Reliability is a problem which unwillingly is considered by professionalists interested scientifically in ropes used in mining hoists. It is generally well-known how difficult is to describe a real wear degree of rope in a particular moment of exploitation time, how difficult to forecast a real wear degree in a next moment of rope inspection. The wearing process of rope is a stochastic process which has several unconvenient properties from identification, estimation and prediction points of view.

The first trial - in Polish papers - of construction of the survival function for mining hoisting ropes has been made in the dissertation [4] where the survival and density functions with regard to time have been built. The criterion of rope withdrawing the velocity of increasing number of wire brakes proposed by Kowalczyk in 1966 [5] was assumed. This velocity is the rope weakness measure. It was taken into account that ropes were of different construction and length, constructing the so-called rope equalizer-function allowing to compare the weaknes of ropes of different geometro-construction parameters. Obtained in such a way the survival function for Polish hoist ropes is shown in fig. 1. One can get more details from the textbook 2 .

In spite of that the investigations to identify the real wearing process of rope continued intensively which has been shown in several papers of the proceedings [7,8], reliability problems of hoisting ropes remaining out of consideration scope.

The paper [3] where three types of rope safety measures - based on the probabilistic approach to the wearing process - were disscused from theoritical point of view, is an exception.

This paper deals with the upper estimation of the survival function for hoisting rope. The relationships between the obtained estimation with regard to the real unkown rope survival function were considered.

2. FORMULATION OF PROBLEM

There is given a hoisting rope of length L, diameter d, construction $s \times \sum_{i=0}^{z} a_i$, where: s - number of strands, a_i - number of wires in a particular strand layers. Let us mark by δ the diameter of rope external wires. Let us assume that:

1) rope wears fatiguley only; wires break as the result of such type of wearing only,
2) wires rope breaks are random only in the whole rope length,
3) estimations of the parameters α and β of equation which describes the total number of wire rope breaks in time $(0,t)$

$$n_t = \alpha t^{\beta} \xi_t, \tag{1}$$

where: ξ_t - random model component, $E\{\xi_t\} = 0$,

are known.

If the exploitation of rope is sufficiently long then the rope rupture occurs. It will take place when the number of wires breakes on k_r lay lengths is such one that the hitherto wearing process of rope changes its character for catastrophic one. Let us assume that

4) rope should be withdrawn when the number of wires breakes on k_r lay lengths will be A% of load-carrying crossection area of rope F_0.

For such formulated wearing process of hoisting rope - when techno-exploitation paremeters of rope are known, it is possible to construct the estimation of the survival function of rope for stipulated period of time.

3. CONSTRUCTION OF ESTIMATION OF THE SURVIVAL FUNCTION

It is known that each broken wire can carry again full load when the distance from the break is $k_r/2$ lay lengths. It is the result of rope construction. If a broken wire can carry again full load it means it can break once more fatiguely.

Let us find the number of possible breaks.

It is known that wires of external layer will break first of all. Therefore the maximal number of theoretically possible breaks will be

$$n_d = \nabla\left(\frac{4AF_o}{\pi\delta^2}\right) \quad (2)$$

where: $\nabla(x)$ - integer part of number x.

The dead number of wires breaks on k_r lay lengths can be

$$n_k = n_d + 1. \quad (3)$$

When this number occurs rope should be absolutely withdrawn.

Let us find a probability distribution of appearence of n_k breaks of wires on k_r lay lengths in the whole rope.

The lay length is

$$h = k_1 d, \quad (4)$$

where: k_1 - constant depending on type of rope.

For line of L length

$$i_s = L/h, \quad (5)$$

where: i_s - number of lays in the whole rope.

The total number of lays in rope of length L

$$i_k = \frac{i_s}{k_r} = \frac{L}{k_1\, k_r\, d}. \quad (6)$$

Therefore the maximal number of theoretically possible wires breaks in a rope of length L

$$N = (i_k - 1)\, n_d + n_k. \quad (7)$$

When analysing patterns (3) and (7) it is easy to get that

- if the number of breaks wires $n < n_k$ the probability of withdrawing the rope is zero,

- if the number of breaks of wires $n > N$ the probability of withdrawing the rope is a sure event,
- when the number of breaks of wire increases the probability of rope withdrawing increases also for $n_k \leq n \leq N$.

Since the probability function of rope withdrawing with regard to time is the point of our interest, let us consider the pattern (1) now. It allows to find exploitation time of rope, in which particular number of breaks appear. Taking also into consideration function of rope withdrawing, we can get:

$$\bar{R}(t) = \begin{cases} 1 & \text{for} \quad t < (n_k/\alpha)^{\beta-1} \\ \varphi_o - \varphi t^{\beta} & \text{for} \quad (n_k(\alpha)^{\beta-1} \leq t \leq (N/\alpha)^{\beta-1} \\ 0 & \text{for} \quad t > (N/\alpha)^{\beta-1} \end{cases} \qquad (8)$$

where:

$$\varphi_o = \frac{N}{N - n_k}, \qquad \varphi = \frac{\alpha}{N - n_k},$$

$\bar{R}(t)$ - the survival function of rope.

An example picture of function $\bar{R}(t)$ is shown in fig. 2.

4. DISSCUSSION OF RELATIONSHIPS BETWEEN FUNCTION $\bar{R}(t)$ AND THE REAL RUN OF THE SURVIVAL FUNCTION $R(t)$

Let us make some remarks.

1) Let us consider a real run of wearing process of hoisting ropes. Steel wires of rope can wear:

- fatiguely only,
- fatiguely and corrosively,
- fatiguely and abrasively,
- fatiguely and corrosively and abrasively.

The most advantageous with regard to wear degree in stipulated period of time is wearing process of fatigue character only. Number of breaks in a rope when corrosion/abrasion appear additionaly will always be not less then that for fatigue wearing only.

2) Eguation (1) describes failure process in time as

- non-stationary,
- single,
- without contagion,

stochastic process.
This equation was used to construct function (8).
In the light of the latest investigations based on empirical data process n_t is non-stationary, single and without contagion but in the inception period only. Contagion appears earlier than non-singularity. In the random component ξ_t a cyclic factor sometimes exists[1] and oscillations of the pure random component have explosion character[2]. Such explosions are proof construction correctness of the formal description as multiplicat function (1). The variance of the random component is an increasin function of time. Recapitulating it is easy to get that assumption - n_t is the random process non-stationary, single, without contagion - is again the solution the most advantageous with regard to wear degree in time.

3) The above two points concern certain proporties of the whole length of rope. Let us make an observation in ecploitation time of such rope parts of k_r lay lengths which have the maximal number of breaks. It is easy to notice that after a certain period of time, when increasing number of breaks is purely random, some rope parts where breaks increment is systematic one, appear. It is a proof of "contagion"[3] as a result of hitherto fatigue and weakness as an effect of appeared breaks - fig. 3. Therefore it is justified that the real run of wear is worse than assumed for construction of function (8).

All the above authorizes to make a conclusion that the real run of rope wear will not be better than that taken into consideration for construction of reliability function.
If we realize at the and that construction of number N is the maximum number of breaks theoretically possible only (practically will be "worse" always) then one can state that obtained estimation (8) of the survival function is the upper estimation[4]. It means that the real run of the survival function will always be beneath of the curve R(t),

$$\bigwedge_t R(t) < \bar{R}(t). \tag{9}$$

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1) First time it was stated in the paper [1].

2) Investigations were based on test presented in [6].

3) A different type of "contagion" appears when a rupture process starts to occur in a rope.

4) After study of paper [9] one can realize how important for reliability considerations posses such assessment.

It seems interesting to resume further empirico - theoritical investigations to find general relationship between the upper estimation in statistical sense of process realization and shown here the upper estimation of survival function based on physical aspects wearing process.

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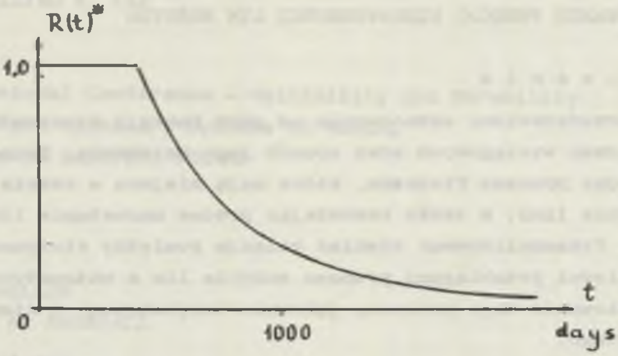


Fig. 1. Survival function for Polish triangle strand hoisting ropes in 1970-73

Rys. 1. Funkcja trwałości polskich trójkątnosplotowych lin wyciągowych w 1970-73

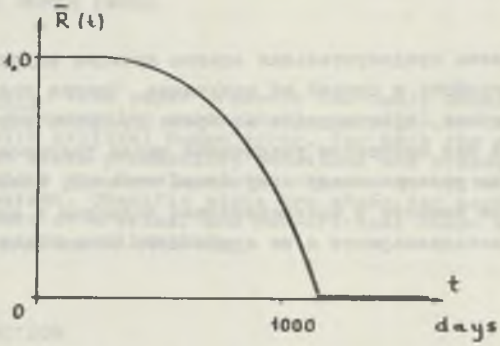
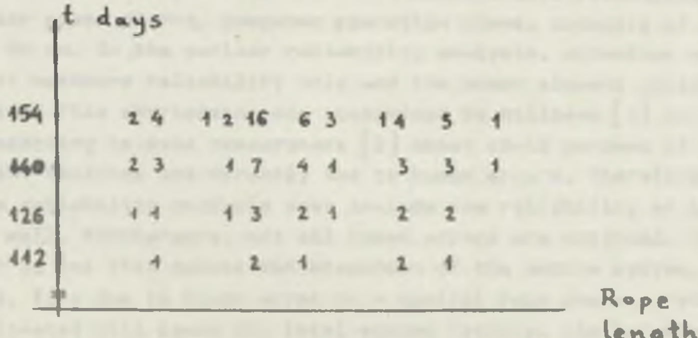


Fig. 2. An example plot of the upper estimation of survival function

Rys. 2. Przykładowy wykres "oceny od góry" funkcji trwałości



Rys. 3. Number of breaks as a function of rope length and exploitation time

Rys. 3. Liczba pęknięć jako funkcja długości liny i czasu eksploatacji

GÓRNE OSZACOWANIE FUNKCJI NIEZAWODNOŚCI LIN NOŚNYCH

S t r e s z c z e n i e

W pracy przedstawiono oszacowanie od góry funkcji niezawodności lin nośnych urządzeń wyciągowych oraz sposób jego uzyskania. Oszacowanie uzyskano analizując procesy fizyczne, które mają miejsce w czasie realizacji procesu zużycia liny, a także rozważając proces narastania liczby pęknięć drutów liny. Przeanalizowano również relacje pomiędzy otrzymanym oszacowaniem, możliwymi przebiegami procesu zużycia lin a matematycznym podejściem do modelowania tego procesu, jako niestacjonarnego i niepojedynczego procesu losowego.

ПРЕДВАРИТЕЛЬНАЯ ОЦЕНКА ФУНКЦИИ НАДЕЖНОСТИ НЕСУШИХ КАНАТОВ

Р е з ю м е

В работе представлена предварительная оценка функции надежности несуших канатов подъемных устройств и способ её получения. Оценка получена при анализе физических процессов, происходящих во время процесса износа каната, а также при размышлениях над процессом увеличения числа разрывов проволоки каната. Проанализированя реляция между полученной оценкой, возможным протеканием процесса износа канатов и математическим подходом к моделированию этого процесса как нестационарного и не единичного стохастического процесса.