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SERVICE LIFE PREDICTION OF RUNNING STEEL WIRE ROPES

PREDVIĐANJE VEKA ČELIČNOG ŽIČANOG UŽETA U EKSPLOATACIJI

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- service life
- prediction

Abstract

Very high strength enables wire ropes to support large tensile forces and to run over sheaves with relative small diameters. Very high strength steel wires had already been in existence for more than a hundred years when patenting, a special heating process was introduced and the drawing process improved. Since then, further improvements have only occurred in relatively small steps.

Wire ropes always have a limited service life. Therefore they must be inspected and examined at regular intervals so that they are replaced well before failure.

End-users of machinery with steel wire ropes, however, would like to have a rough estimation of the service life of the ropes already in the early stages of conceiving their machines, so that they can, if necessary, improve the reeving system. This is one of the reasons why for many years extensive research is carried out in order to improve calculations for predicting the service life of wire ropes. This paper is meant to offer an overview information on the method of calculation and to demonstrate the potential and limitations of the forecasting procedure for service-life prediction of running steel wire ropes.

Ključne reči
- čelično žičano uže
- radni vek
- predviđanje

Izvod

Vrlo visoka čvrstoća omogućava žičanom užetu da prenese velike zatezne sile i da se kreće po koturima relativno malog prečnika. Žice od čelika vrlo visoke čvrstoće su postojale više od sto godina pre nego što su patentirane, kada je uveden specijalni postupak zagrevanja i usavršen postupak izvlačenja. Dalja poboljšanja posle toga su uvedena u relativno malim koracima.

Žičana užad uvek imaju ograničen radni vek. Zbog toga ona moraju da se podvrgnu inspekciji i ispitaju u pravilnim intervalima da bi se zamenila znatno pre otkaza.

Krajnji korisnik mašine sa čeličnim žičanim užetom u svakom slučaju želi da ima grubu ocenu radnog veka užeta već u ranoj fazi razvoja mašine. tako da bude u mogućnosti, ako zatreba, da poboljša sistem mašine. To je jedan od razloga zbog kojih su tokom niza godina izvedena obimna istraživanja kako bi se poboljšali postupci proračuna za predviđanje radnog veka žičanih užadi. Namena ovog rada je da ponudi pregled informacija o postupcima proračuna i da prikaže mogućnosti i ograničenja postupaka prognoziranja za predviđanja radnog veka čeličnih žičanih užadi u eksploataciji.

INTRODUCTION

The wires in wire ropes are stressed by fluctuating tension, bending, pressure and torsion. For a long time wires have been tested in different testing machines under one or a combination of these fluctuating stresses. The tests with combined stresses, especially bending and pressure, have been done with the aim to imitate the stresses in a wire rope. However, the test results do not come up to expectations, or only imperfectly. Wire endurance, for example, has even been increased when the wires, loaded by fluctuating bending, are loaded in addition by fluctuating pressure. This effect can probably be attributed to a strain hardening of the wire surface.

Nowadays, wire fatigue tests are normally tests with only one fluctuating stress, mostly a longitudinal stress. The test methods with fluctuating longitudinal stresses are:
- tensile fatigue test (wire under fluctuating tensile force),
- simple bending test (fluctuated bending of the wire over one sheave),
- reverse bending test (fluctuating bending of the wire over two sheaves or sheave segments),
- rotary bending tests (wire bending by rotating the wire).

For these test methods, the principle wire arrangement in the test machines is shown in Fig. 1. The fluctuating longitudinal stress affects different zones of wire cross-sections. Wire cross-sections with zones of the highest fluctuating longitudinal stress are also shown below the wire arrangements in Fig. 1. The highest stressed zones are shaded. The highest fluctuating longitudinal stress is taken as nominal fluctuating stress. For fatigue strength (infinite life), instead of the stress, the symbols σ are written with indices as capital letters. In Fig. 1, the stress amplitude σ_a and middle stress σ_m are listed for general cases in fatigue tests. Below them the stresses are listed for the special cases alternate stress σ_{alt} and repetitive stress σ_{rep}.

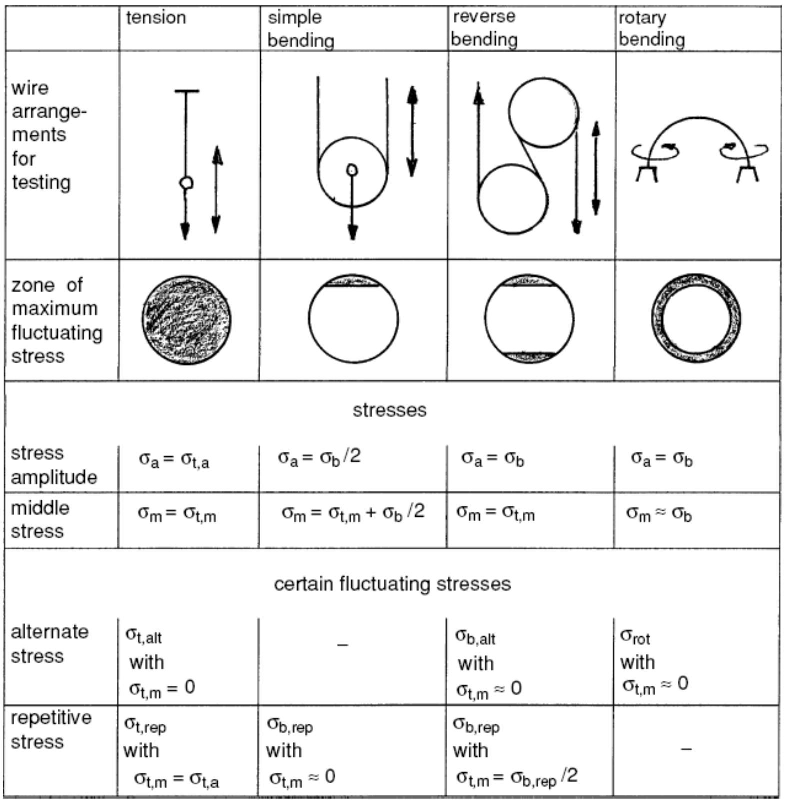

Figure 1. Wire arrangement for fatigue tests, zone of maximum stress amplitude, stress amplitudes and middle stresses, /1/.
Slika 1. Prikaz žice za zamorno ispitivanje, zona maksimalne amplitude napona, amplituda napona i srednji napon, /1/

CALCULATING THE NUMBER OF SUSTAINABLE BENDING CYCLES

Rope researchers like Benoit, Wörnle and Müller carried out a vast number of wire rope bending fatigue tests. They examined the effect of essential factors of influence on the service life of the rope. Prof. Feyrer from the University of Stuttgart has summed up their findings in a formula which allows to predict the service life of wire ropes in reeving systems with sufficient accuracy. The Feyrer formula reads:

$$\lg N = b_0 + \left(b_1 + b_4 \times \lg\frac{D}{d}\right) \times \left(\lg\frac{Sd_0^2}{d^2 S_0} - 0.4\lg\frac{R_0}{1770}\right) + $$
$$+ b_2 \times \lg\frac{D}{d} + b_3 \times \lg\frac{d}{d_0} + \frac{1}{b_5 + \lg\dfrac{\ell}{d}}$$

In this formula: N – indicates the number of bending cycles; d – nominal rope diameter in mm; D – diameter of the sheave in mm; S – rope line pull in N; ℓ – length of the most heavily strained rope zone in mm; R_0 – nominal tensile strength of the wire in N/mm^2; S_0 (= 1 N/mm^2) and d_0 (= 1 mm) are unit line pull and unit diameter which make the fractions dimensionless. Factors b_0 to b_5 are rope-specific parameters which must be determined separately in a great number of bending fatigue tests for every single rope design.

Average number of bending cycles $\tilde{N}$

By means of statistical procedures it is possible to determine factors b_0 to b_5 for different reliabilities of the predictions. For instance, the commonly quoted average number of bending cycles $\tilde{N}$ is the number of bending cycles which, under given circumstances, would be achieved in a great number of tests as the average value of all test results of a certain rope design.

Normally the average number of bending cycles is the value which the designer or operator of a crane is eager to know. He is interested in the number of bending cycles that he will achieve on average. However, he must bear in mind that average value also indicates that in a great number of tests one half of all the wire ropes will exceed that value whereas the other half will not reach it.

That means that a number of bending cycles defined as the average value of a great number of tests can under no circumstances be guaranteed for one single wire rope by the rope's or the crane's manufacturer: The term average value itself implies that half of all ropes do not achieve that value.

The number of bending cycles $\tilde{N}$

There are situations in which it does not suffice to know that the wire rope will achieve the calculated number of bending cycles on average. It's rather a question of determining a number of bending cycles which will be achieved with a high probability by nearly all the ropes in operation. However, the statistical spread of the test results during bending fatigue tests indicates that it is virtually impossible to predict a number of bending cycles which will be achieved in any case. Therefore a number of bending cycles N_{10} is calculated which is achieved by 90% of all wire ropes tested at a probability of 95%, and only 10% of all the ropes tested do not achieve that value. It is self-evident that the number of bending cycles N_{10} must always be smaller than the average number of bending cycles $\tilde{N}$.

The definition of a bending cycle

A bending cycle is defined as the change from the straight state of the rope into the bent state and back again into the straight state (symbol) or as the change from the bent state into the straight state and back again into the bent state of the same direction (symbol). Whenever a rope runs over a sheave, the respective rope zone carries out a complete bending cycle (i.e. a change from the straight- into the bent- and back again into the straight state); whenever a rope runs onto a drum it carries out half a bending cycle (i.e. a change from the straight into the bent state).

The definition of a reverse bending cycle

A reverse bending cycle is defined as the change from the bent state into the straight state and again into the bent state, but of the opposite direction (symbol).

Practice, however, shows that not only the angle between the bending planes decides if the damage of the rope is greater than in the case of a simple bending cycle but also the distance between the sheaves which have been arranged under such an angle. So, with short distances between the sheaves the damage to the wire rope is already considerably greater at an angle of about 90° than with a simple bending cycle, so that case should be defined as a reverse bending cycle, whereas with great distances between the sheaves very often there is hardly any negative effect on the service life of the rope, even at angles of 120° and more, because the wire rope can rotate between two sheaves around its axis for exactly that angle, so that finally it runs over both sheaves in the same bending direction.

SERVICE LIFE PREDICTION

It is possible to calculate, based on Feyrer's formula, for a set of given parameters (rope design, nominal rope diameter, diameter of sheaves, line pull, nominal wire tensile strength and length of most heavily strained rope zone), the sustainable average number of bending cycles $\tilde{N}$ until rope discard and rope break, as well as the number of bending cycles N_{10} until rope discard and rope break, which 90% of all ropes achieve with a 95% probability.

Figure 2 shows the illustration of the average number of bending cycles until rope discard (lower curve) and until rope break (upper curve) as a function of nominal rope diameter. Figure 3 shows the number of bending cycles until rope discard (lower curve) and until rope break (upper curve) as a function of sheave diameter. With increasing sheave diameter the numbers of bending cycles increase over proportionally. Figure 4 shows the number of bending cycles until rope discard (lower curve) and until rope break (upper curve) as a function of chosen line pull. The diagram clearly illustrates that with increasing line pull the numbers of bending cycles decrease over proportionally.

Factors of influence which are not taken into account in calculations are corrosion, lubrication, abrasion, groove material, shape of grooves and fleet angle, and also tension-tension stresses (A wire rope does not only fatigue because of bending cycles running over sheaves or drums, but also because of repeated changes of line pull. Therefore even a standing rope, which never runs over a sheave, as for instance the suspension rope of a crane jib, has a limited service life which normally is several times higher than the service life of running ropes of the same installation).

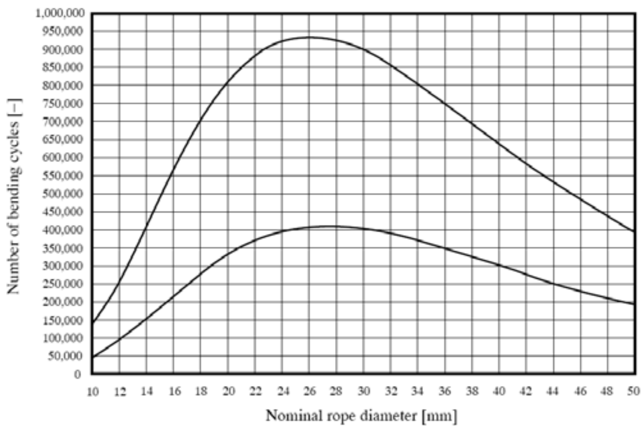

Figure 2. Number of bending cycles vs. nominal rope diameter: rope discard (lower curve) and rope break (upper curve).
Slika 2. Zavisnost broj savojnih ciklusa od nazivnog prečnika užeta: zamena užeta (donja kriva) i lom užeta (gornja kriva)

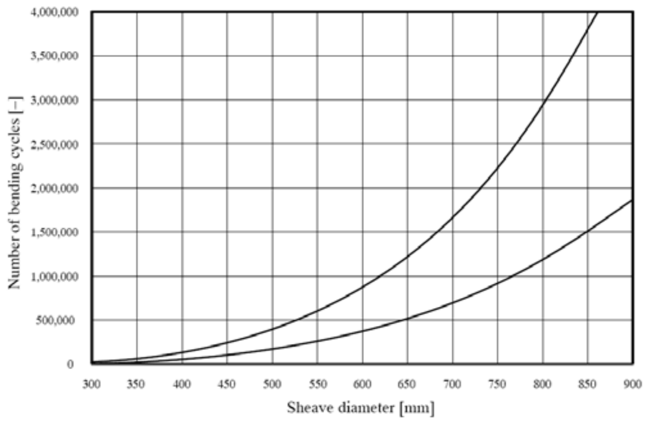

Figure 3. Number of bending cycles vs. sheave diameter.
Slika 3. Zavisnost broja savojnih ciklusa od prečnika točka

For calculating wire rope service life, the following information is required:

1. Detailed documents about the reeving (sketch and/or design drawings), and information on the mode of operation
2. Rope design
3. Nominal rope diameter
4. Sheave diameter
5. Drum diameter
6. Line pull (e.g. 20 000 N) or the load collective per line (e.g. 10 000 N in 60% of all hoisting cycles, 25 000 N in 40% of all hoisting cycles).

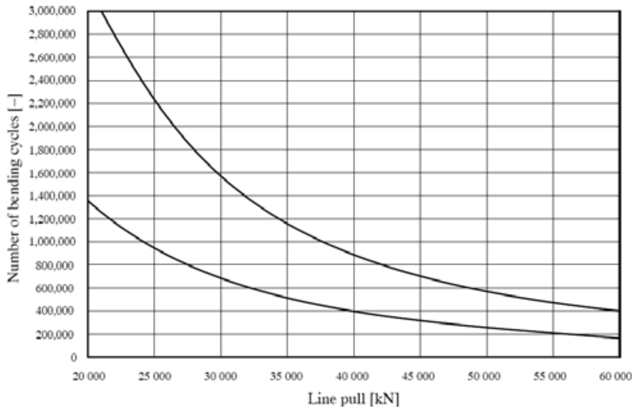

Figure 4, Number of bending cycles vs. line pull: rope discard (lower curve) and rope break (upper curve).
Slika 4, Zavisnost broja savojnih ciklusa od linijskog zatezanja užeta: zamena užeta (donja kriva) i lom užeta (gornja kriva)

The influence of load collective

The number of bending cycles which can be achieved in a reeving system depends on many factors of influence. Under the same conditions a high-quality rope, for instance, will easily achieve three times the number of bending cycles of a simple rope design. Similarly, a well-lubricated and regularly relubricated wire rope will normally achieve a much higher number of bending cycles than an insufficiently lubricated rope of the same design. Another important factor of influence is the crane's mode of operation.

When the designer classifies the crane into a group of mechanisms of the standard he already decides whether the rope of his crane will enjoy a long or only a very short service life, because it depends on that classification whether the reeving system will lift the same load with a thick or a thin wire rope and whether that rope will run over sheaves with a great or a small *D/d*-ratio. Ropes in the highest group of the mechanism will achieve approximately 200 times the number of bending cycles compared to their counterparts from the lowest group of the mechanism.

In the past it was suggested to state in the standard the expected number of lifting cycles of a rope as a function of the group of mechanism. However, ropes in reeving systems of the same group of mechanism do not necessarily achieve the same service life, not even if the reeving systems are identical. The reason is reeving systems within the same group of mechanism can operate with very different load collectives, /2/.

THE INSPECTION OF STEEL WIRE ROPES

DIN 15 020, Sheet 2, Point 3.4 "Monitoring" recommends daily visual inspection of wire ropes and rope end connections for potential damage.

In addition, at regular intervals, wire ropes must be inspected by qualified personnel as to their operational safety. According to DIN 15 020 the intervals must allow for "any damage to be recognised in good time". Therefore the intervals need to be shortened, compared to the rest of the service life, during the first weeks after the installation of a new wire rope and after first wire breaks have occurred.

After abnormal loading or in the case of presumed non-visible damage, the intervals must be reduced, if necessary, to hours. The rope must also be inspected before starting up machinery again after lying idle for an extended period. The same applies to lifting systems that have been dismantled for a change of location before any operation at the new site. This also applies whenever an accident or any damage has occurred in connection with the reeving system.

According to DIN 15 020, sheaves, rope drums and compensation sheaves "must be examined if the need arises and whenever a new rope is installed. Such examinations should be conducted at least once a year."

Regular inspections of the reeving system contribute to safety and cover the operator in two ways. First, the risk of accidents is reduced. Second, should equipment damage occur, detailed documentation of regular monitoring would demonstrate that the operator has not been careless or negligent, /3, 4/.

CONCLUSION

A steel wire rope is a product exposed to inconvenient conditions and high loads during operation with a limited lifespan. Many properties will change during its service period. For instance, breaking strength will increase slightly at the beginning of its service life but may rapidly decrease after reaching this maximum.

The initial increase of the breaking strength is a consequence of settling-in effects (within the rope) which lead to a more homogeneous load distribution amongst wires in the rope. The subsequent decrease in breaking strength can be explained by increasing loss of metallic cross-sectional area caused by abrasion and corrosion, by the occurrence of wire breaks and by structural changes to the rope.

As already mentioned, because of the statistical nature of the predictions and because of the many additional factors of influence on wire rope service lives, calculated values can under no circumstances be guaranteed.

The key value of these calculations is in combination with application of proper maintenance and inspection procedures. This makes it possible to discard the rope in good time and recognising weak areas in the reeving system. Once these have been identified, measures can be taken to prevent such damage from occurring again.

ACKNOWLDEGEMENT

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