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CREEPAGE OF STEEL CABLES, DAMAGED BY CONTACT AND FRICATIVE CORROSION

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The mathematical model of creepage determination for steel ropes, taking into account the contact and fricative corrosion, methods of determination of the thermo electro destroying force and electro chemical characteristics, algorithm for determination of the steel cable corrosion speed are considered in the article.

Запропоновано критерії експлуатаційної міцності канатів пошкоджених корозією. Розроблено алгоритм визначення швидкості корозії дротів сталевих канатів. Наведено приклади окремих видів антикорозійного захисту.

Introduction

Steel ropes are used to provide firmness of steel masts and pipes.
During the process of exploitation the ropes are subjected to atmosphere, sun radiation, icing, electric currents, vibrations, air and the like.
To evaluate the remaining resource of the steel rope determination it is necessary to determine the damage rate of ropes and wires, with respect to basic factors, which cause corrosion.
Purpose of work – to determine main factors of steel ropes corrosion, to build correlations, which determine corrosion speed, to build the algorithm of experiments operation for determination the steel ropes remaining resource.
According to GOST 3241-91 ropes are distinguished:
– by configuration: single, double, triple spin;
– by the transversal cut: round, flat;
– on strands transversal cut: round-strand and gusset-strand.
By the spin type of strands and ropes of a single spin:
– with the dot touch of wires between layers PC;
– with the linear touch of wires between layers LC;
– with the linear touch of wires between layers at the identical diameter of wires on strands layers LC-I;
– with the linear touch of wires between layers at different diameters of wires in an external strand layer LC-D;
– with the linear touch of wires between layers and wires of filler LC-F;
– with the linear touch of wires between layers and which have layers including wires of identical diameter in the strand LC-DI;
– with the combined dot-linear touch of wires DLC.

By the type of wire surface covering in a rope:
– wires without covering, the zinc-coated wires (depending on the surface closeness of zinc: A, R, WR);
– rope or strands covered with polymeric materials P.
As wires in a rope are in a contact and there can be cracks between them, the processes of contact and fricative corrosion can develop.

Creepage of steel ropes

Deformation of wire in a steel rope can be determined through the dependence:

$$\eta_x d(\Delta L / L)dt = f / A,$$

where L is the wire (rope) length before deformation;
f / A is the force, which is distributed over the transversal cross-section area unit;
A is the section area.
In turn:

$$f_x \approx kT \frac{\nu_0}{V} \frac{\Delta L}{L} \text{ under } \Delta L \to 0,$$

where k is the material constant;
T is the absolute temperature;
ν_0 / V is the quantity of wires per unit of rope volume.
If a wire is damaged by corrosion on depth δ, than the area of section A will be equal to: $\pi(D-2\delta)^2/4$ where D is the wire diameter.
The behavior of wire in a steel rope recalls the behavior of a viscoplastic body. The tension in a wire in the axis direction equals:

$$\sigma = E\varepsilon + \eta\dot{\varepsilon}.$$

Under the constant loading deformation values depend on loading time:

$$\varepsilon = \frac{\sigma}{E}\left[1 - \exp\left(\frac{-t}{\eta / E}\right)\right],$$

where η is the viscosity coefficient.

Respectively under unloading from value ε_0 after the tension removal

$$\varepsilon = \varepsilon_0 \exp\left(\frac{-t}{\eta / E}\right).$$

The Jung module depends on the loading duration:

$$E(t) = \sum_{i=1}^{n} E_i e^{-t/\tau_i},$$

where E_i is the Jung modules of relaxation spectrum;

t is the duration of loading action.

Under step-by-step loading the following expressions should be used

$$\varepsilon(t) = \sum_{t_i=-\infty}^{t_i=t} \Delta\sigma_i J(t - t_i);$$

or

$$\sigma(t) = \sum_{t_i=-\infty}^{t_i=t} \Delta\varepsilon_i E(t - t_i),$$

where t_i is the time, when a next step (i) of loading began;

J is the compliance.

It should be noted that there can exist two limit types of the rope loading.

If a rope stretches at a constant speed of length $\dot{\varepsilon}$ increase till the deformation ε at which it is fixed and the tension relaxation begins. Residual tensions in the rope wires are determined by the formula:

$$\sigma^* = \frac{\varepsilon}{t}\int_0^t E(t)dt,$$

ore

$$\sigma^* = \frac{\varepsilon}{t_1}\int_0^t H_L \tau\left[\exp\left(-\frac{t - t_1}{\tau}\right) - \exp\left(-\frac{t}{\tau}\right)\right] d\ln\tau,$$

where H_L is the relaxation spectrum under tension;

t_1 is the time period from the relaxation beginning;

τ is the relaxation period;

t is the full time.

Compliance under creepage is determined from the formula:

$$J(t) = J_g + \frac{t}{\eta} + \sum J_i\left[1 - \exp\left(\frac{t}{\tau_i}\right)\right],$$

where J is the compliance of the straight wire, that takes into account a resilient constituent;

J_i is the compliance of individual wire, with the aftereffect resilient;

$1/J(t)$ is the creep modulus.

The algorithm of contact and fricative corrosion speed determination is shown in figure.

The steel rope wire contact corrosion

In the air-saturated environment the reaction of the oxygen ionization as a result of the electrons diffusion happens.

The total cathode current in the formed galvanic couple is directly proportional to the area of the wires contact.

One of wires is considered to be a cathode, and another – an anode.

If the ratio of cathode to anode areas is equal to ***n***, than it is possible to calculate the corrosion current:

$$i_{cor} \cong i_D n,$$

where i_D is the current density in the galvanic couple, mk A/cm^2.

The temperature of the contact corrosion below which the wire steel isn't submitted to the influence of corrosion in the hostile environment solution can be find from to the formula:

$$T_{CC} = d_1 + d_2 C_{Fe} + d_3(C_c - d_4),$$

where d_1, d_2, d_3, d_4 are coefficients;

C_F, C_C are steel elements concentration, mol/l.

Potential of metals of a couple under the contact corrosion of one metal wire (Fe) and another metal wire (Zn, Fe) in the moist and possibly aggressive environment is determined through the dependence :

$$\varphi_{Fe} = f_1 + f_2 \lg i + f_3 S_{Fe} + f_4 T + f_5 C,$$

where f_1, f_2, f_3, f_4 are coefficients;

S_{Fe} is the area of steel wire contact;

T is the metal temperature;

C is the hostile environment concentration, $\mathrm{n \cdot mol}$.

Fricative corrosion

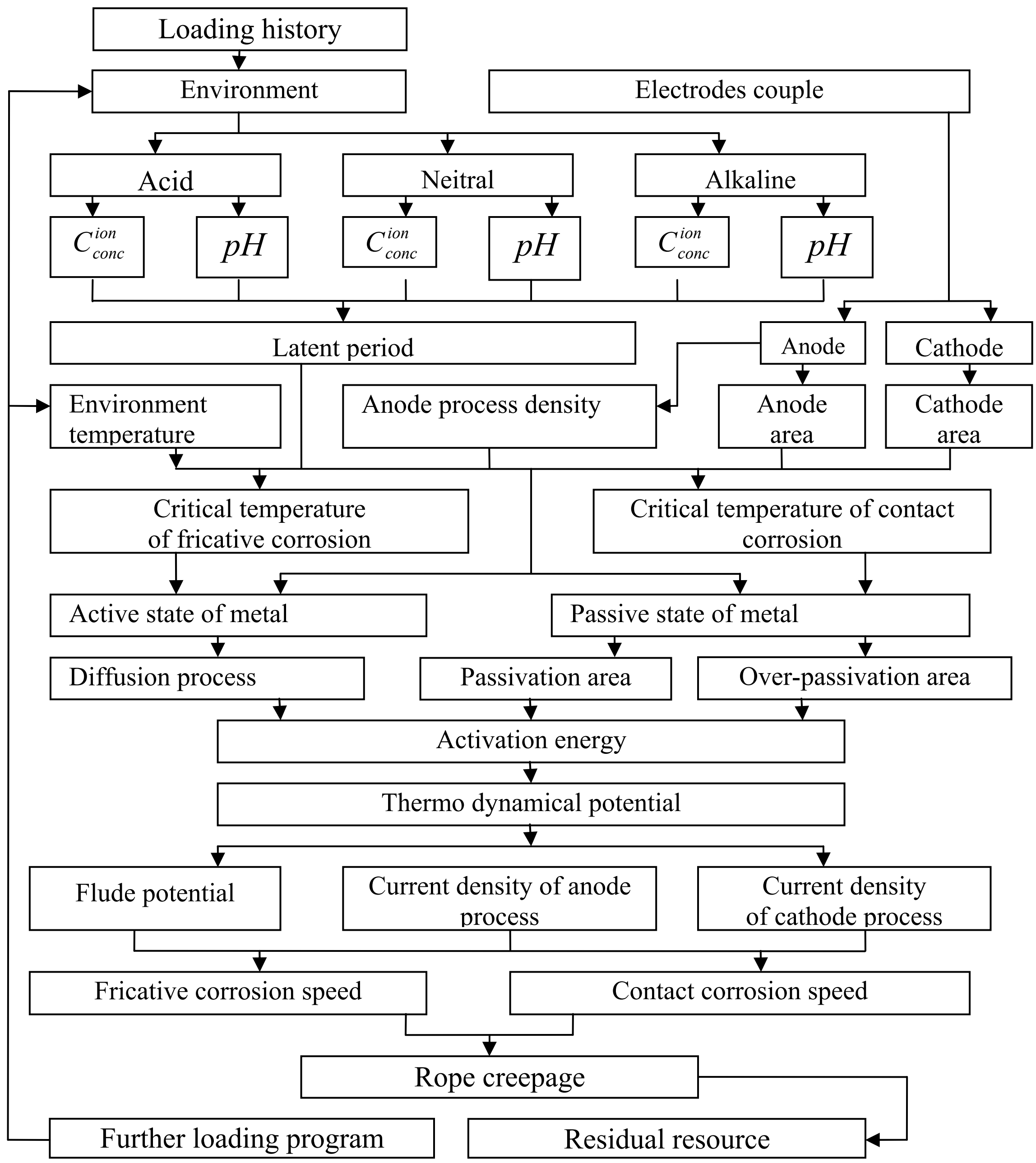
Because of diffusion during the fricative corrosion the migration of corrosion products migration and the oxygen migration into crack develops. As a result, the presence the of oxygen and metal ions in the rope kernel, can influence the acid-base balance ratio (pH).

Time of the latent period τ before the corrosion begins can be determined through the relation:

$$\tau = 9600\, I\,[10^{-pH} + 10^{(a_1 - a_2 pH)}]/i,$$

where I is the average crack width, mm;

i is the anode current density in the passive state, mk· A/cm^2.



Algorithm of creepage determination of steel ropes, taking into account the contact and fricative corrosion

The more intensive the migration of contaminating environment ions, the more the current density in the crack:

$$i_f = DF(C_f - C_o)/1000\,\delta,$$

where C_o is a contaminant ions concentration in an environment; δ is the crack width, cm;

The critical temperature of the fricative corrosion beginning is increasing together with the increase of steel components concentration, secundum to relation:

$$C_{CTF} = a_0 + b_1 C_C + b_2 C_{Fe} + b_3 C_x,$$

where b_1, b_2, b_3, b_4 are the coefficient; C_{Fe}, C_C, C_x are the concentration of the steel components (carbon, iron and alloying components). The passive state is characterized by the full passivation potential. The other name is fludepotential φ_{f_l}. Under constant pH for certain group of metals the ratio is:

$$\varphi_{fl} = \frac{g_1 Z_{MEnOm}}{nm + g_2},$$

where g_1, g_2 is the constant;

φ_{fl} is the thermodynamics potential of the metals lower oxide, attributed to the gramme-equivalent of metal:

$$\varphi_{fl} = \frac{g_1 Z_{MEnOm}}{nm}.$$

The thermoelectromotive force determination

During the contact of two heterogeneous metals transition of the charge carrier from one metal to another is observed out, until the difference of potentials, whish resists the subsequent transition and equals the difference of the Fermi energy levels of both metals(cathode and anode) will not diminish.
In the presence of temperature gradient, in the point contact of two metals there arises the thermo diffusion of electrons towards the lower energies direction – from a hot area to a cold. Thermoelectrodestroying force, that arises up as a result of the directed thermo diffusion of electrons, is the kinetic electronic distinction of a metal.
To determine the thermoelectrodestroying force on the surface of separate wires, micro probes and an TEM-2 device are used.

Studying of the steel rope sample electrochemical characteristics

To determine the rope sample electrochemical characteristics electrode potentials and readings of anode and cathode polarization curves by galvanostatic and controlled potential methods are used.
The quantitative relative coefficients of sample with the defects of the corrosion quality are the coefficients

$$K_{cm} = \frac{\varphi_m}{\varphi_c} \ge [K_{cm}] \to 1,$$

where φ_c is the electrode potential of the area of the sample with the lowest firmness

$$K_{cm\%} = \frac{\varphi_c - \varphi_m}{\varphi_m} 100 \le [K_{cm\%}] \to \min,$$

where φ_c, φ_m are absolute average values of macro-potentials with corrosion and without corrosion respectively;
$[K_{cm\%}]$ are legitimate values of the coefficient.
Similar relative coefficients can be received relative to the density of the anode current from polarization curves for every wire.

Test of the ropes damaged by corrosion

The test of wire on tension is executed according to GOST 10446.
The test on torsion is executed according to GOST 1545. The test of wire on a bending is executed according to GOST 1579.
Quality of the zinc coverage must be tested according to GOST 7372.

The total bursting effort of all wires in a rope B in Newtons is calculated according to the results of tests on tension of wires damaged by corrosion by the formula:

$$P = \sum_{1}^{i} \left[\left(\sum_{1}^{z} \left(R \frac{\pi}{4} (D_Z - 2\delta_Z)^2 \right) \frac{n}{Z} \right) \right],$$

where i is the quantity of identical diameter wires groups;
z is the quantity of tests of wires diameter groups;
R is the breaking strength limit for wire steel, Pa;
D_Z is the z group wire diameter, m;
δ_Z is the z wire of group corrosion depth;
n is the quantity of wires of each group by their diameter.
The test is considered to be valid, if the breaking strength of wires is adequate to the gauge standard requirements. There can be applied no more than 80 % of minimum breaking strength simultaneously, as is indicated in the corresponding standards in assortment.
The residual loading is applied gradually together with the speed of tensions applying, which is equal the 10 N/mm^2 per second. The actual breaking strength is the strength, when there is no possibility to increase loading.

Bracing wire protection in the point of contact with foots located in the soil

To prevent the soil corrosion, it is necessary, for the potential drop between the cathode and anode areas be equal to zero; and the electrical resistance of the corrosion element current should be very high, due to isolation.
Potential, at which the corrosion stops, is named the protective potential, and the current density, that provides the change of potential to the protective - protective one, is named the protective closeness of current.
Tread protection of steel ropes is carried out by electrodes-protectors, which have a more negative potential and together with the protecting rope serve as anode.
Tread amount n, necessary to protect the construction protection, depends on the area of protected surface S, the minimal density j under which $j_{cm} = 0{,}016$ A/m^2, coefficient k, which is characterizing construction protection.
The tread's current intensity is determined according to the formula:

$$n = \frac{I_{pr}}{i_{pr}} = \frac{kjS}{i_{pr}}.$$

The tread durability in years is determined by the formula :

$$T = \frac{0{,}114\, Mg\, D}{i_{pr}},$$

where M is the tread mass, kg;

g is the electrochemical equivalent of tread material, 4/кг;

D is the tread efficiency;

i_{pr} is the protective current in the chain "tread-steel rope", A.

The cathode protection of steel ropes is provided by a direct electric current which flows through the anode earth. The negative electrode of direct current joins with a cathode – protective steel rope, and a positive electrode joins with an anode.

A rope is polarized negatively; its potential becomes the negative potential of the corrosive anode couples and the corrosion current stops.

Under such a protection an auxiliary electrode, through which the current flows down into soil, collapses.

The necessity of the cathode protection is determined by index B depending on the specified rope longevity:

$$B = \frac{\tau - (\delta_0 - \delta_1)}{V_k},$$

where τ is the rope longavity, year;

δ_0 is the initial width of metal, mm;

δ_1 is the allowable residual width of metal, mm;

V_k is the corrosion speed, mm/year.

If $B \le 0$ there is no need in the cathode protection; if $B > 0$ the protection is obligatory.

The exploitation strength criteria for steel ropes, damaged by corrosion

$$K_{cm} = \frac{\Pi_c}{\Pi_m} \ge [K_{cm}] \to 1$$

or, in percent:

$$K_{cm\%} = \frac{\Pi_m - \Pi_c}{\Pi_m} 100 \le [K_{cm\%}] \to \min$$

$$K_c = \frac{\Pi_c}{\Pi_C} \ge [K_c] \to 1;$$

$$K_{c\%} = \frac{\Pi_c - \Pi_c}{\Pi_C} 100 \le [K_{c\%}] \to \min,$$

where Π_C is the standard value of strength index; Π_m is the strength index of the wire main metal ; Π_c is the strength index of the metal, damaged by corrosion;

$[K_{cm}]$, $[K_c]$ are the admissible value of coefficients.

Conclusions

Algorithm and correlations for creepage determination of steel ropes, taking into account the contact and fricative corrosion are constructed.

The method of testing and determination of the electro-destroying force of steel ropes, damaged by corrosion is offered.

The criteria of operating durability of ropes, damaged by corrosion are proposed.

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