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MATHEMATICAL MODELS OF DISTRIBUTION OF THE PROTECTIVE POTENTIAL OF UNDERGROUND MAIN PIPELINE

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ABSTRACT

The theoretical results of research for the development of an information-analytical system for monitoring and control of electrochemical protection against corrosion of main pipelines, carried out within the framework of the grant project of the Ministry of Education and Science of the Republic of Kazakhstan AP 09261098, are presented. There are a large number of publications on the problems of electrochemical protection of underground steel structures, including main pipelines. So, in a popular form, using numerical examples, the regularities of the processes of electrochemical protection and the problems of electrochemical protection are considered as problems of currents in the ground for complex pipeline systems with inhomogeneous parameters.This article proposes stochastic models and methods for solving the problem of operational planning of operating modes of cathodic protection stations for pipelines under conditions of incomplete information when solving the problem of minimizing the cost of operating an electrochemical protection system. As a result of experimental studies of solving the problem of operational planning of the operating mode of the electrochemical protection system, the optimal values of the current strength of the cathodic protection station were obtained, under conditions of incomplete information about the resistance of the pipeline insulation coating and the resistivity of the soil, and the effectiveness of the developed models for solving this problem was shown.

Keywords: stochastic model, simulation method, electrochemical protection, underground main pipeline, information and analytical control system, cathodic protection station, monitoring, corrosion.

INTRODUCTION

One of the main tasks of underground pipeline systems (PS) for the transportation of oil and gas (oil transportation system (OTS) and gas transmission system (GTS)) of the Republic of Kazakhstan (RK) is to increase the durability and operational reliability of main pipelines (MP) (trunk pipelines (TP) and main gas pipelines (MGP)) in order to reduce accidents at their facilities (volumes of leaks of the transported product, prevention of accidents, explosions, etc.) [1-3]. Among the causes of accidents at MT in an approximate percentage are: welding defects - 27.5%; corrosion - 26.8%; factory defect - 19.7%; mechanical damage - 16.4%; others - 9.6%. Corrosion of pipelines is one of the main causes of accidents at MT, shutdowns and repairs of technological equipment associated with welding of caverns, welding of patches, replacement of pipeline sections, loss of transported product and environmental pollution [1-5]. Consequently, the durability and reliability of a pipeline system is highly dependent, on the order of 27%, on its corrosion protection. On the other hand, the electrochemical protection system (EPS) of the MT of the Republic of Kazakhstan is practically not automated, which reduces its reliability and quality due to the impossibility of a quick response to various situations arising during operation, associated mainly with changes in weather conditions and power outages. This leads to an increase in the number of accidents and operating costs. In this regard, the complex automation of the system is one of the most important directions for increasing its efficiency, and, consequently, increasing the durability and reliability of the PS [4, 5]. A sufficient number of mathematical models and algorithms for calculating and optimizing the parameters of ECP MT with their subsequent software implementation have been developed [6, 7]. However, they do not solve the problem of complex automation of the ECP MT system. Recently, developments have been aimed at automating the processes and tasks of the ECP MT system. Thus, various telemechanical systems for monitoring and controlling ECP facilities are known based on telecontrol controllers with integrated GSM / GPRS modems for mobile communications and other communication channels with an automated workstation of a control center [7-9].

MATERIALS AND METHODS

For a section of an underground pipeline with cathodic protection stations (CPS) connected to it, the potential difference "pipe-ground" at each point along the entire length of the pipeline for each RPS is made up of two components: the positive potential of the soil $U^{i}_{soil}(x)$ created by the electric field of the anode ground electrodes, and the negative potential $U^{i}_{T}(x)$ of the surface pipes arising due to the flow of cathodic current along the pipeline. An insulated underground pipeline protected by cathodic protection stations can be represented as an extended DC electric conductor with a leak (Fig. 1).

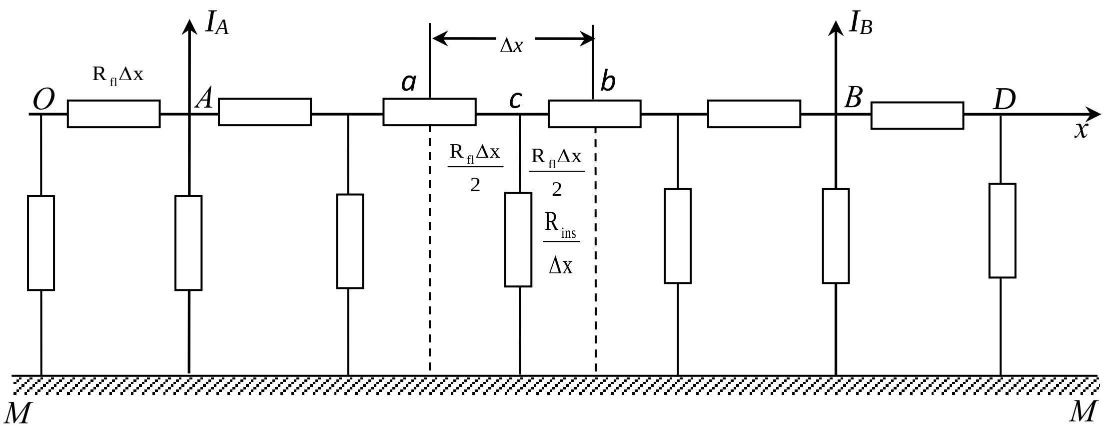

Fig. 1 - Equivalent circuit of a long, leaky conductor

The value R_{fl} [Ohm / m] is the electrical resistance of a unit length of an extended conductor with leakage (specific longitudinal resistance, linear resistance).

The value R_{ins} [Ohm·m] is the contact resistance to leakage, which characterizes the electrical resistance between a piece of an extended conductor and the medium in contact with it.

In the presence of any load applied to an extended conductor, at any point x of the conductor we have, depending on the coordinate x, the potential $U_T^i(x)$ and the current i flowing through the conductor.

Consider the one shown in Fig. 1 equivalent circuit for a long, leaky conductor. Let this circuit be presented in the form of series-connected longitudinal resistance $R_{fl}\Delta x$ elements, to the ends of which the elements of transition resistances are connected in parallel $\frac{R_{ins}}{\Delta x}$. Suppose, in addition, on the OS section there is a certain gap AB, inside which no load is applied to the extended conductor. Due to the fact that the AB gap is not loaded, the current i throughout this gap has no break, i.e. changes continuously.

Let us select on the interval AB a sufficiently small segment ab in length Δx. Let the starting point a of the segment ab have a coordinate x. Therefore, the coordinate of point b is $x + \Delta x$. One of the elements of transition resistances $\frac{R_{ins}}{\Delta x}$ is connected to the midpoint of the segment ab, and therefore between points a and b are included along the longitudinal resistance element having a value $\frac{R_{fl}\Delta x}{2}$.

As can be seen from Fig. 1, this voltage drop is equal to:

$$-\Delta U_T = i\frac{R_{fl}\Delta x}{2} + (i + \Delta i)\frac{R_{fl}\Delta x}{2}, \tag{1}$$

Where Δi is the current in the section between the section of the conductor and the equipotential surface of the MM, i.e. the current Δi is the increment of the current in the section Δx, which will be positive if it enters the segment Δx (leakage current) and negative if it leaves the segment Δx (leakage current).

The magnitude of the current Δi is determined by the potential U_{Tc} of point c and the transition resistance $\frac{R_{ins}}{\Delta x}$, and with a positive value of the potential U_{Tc}, the increment will be negative Δi, and with a negative potential U_{Tc}, the increment is positive.

RESULTS AND DISCUSSION

Thus, with known values of the potential and current at the connection point of the RMS, it is possible to sequentially obtain the values of the potential U_T and current i at each point of the section under consideration.

We represent equations (1.1) and (1.3) as follows:

$$\frac{\Delta U_T}{\Delta x} = -R_{fl}i - \frac{R_{fl}}{2}\Delta i, \tag{1.4}$$

$$\frac{\Delta i}{\Delta x} = -\frac{U_T}{R_{ins}} + \frac{R_{fl} i}{2R_{ins}} \Delta x \triangleleft . \qquad (1.5)$$

If the segment dx is reduced indefinitely, directing it to the value of the differential dx of the coordinate x, then the increments ΔU_T and Δi will accordingly tend to the differentials dU_T and di. The second summands of the right-hand sides of equations (1.4) and (1.5) turn into quantities of a higher order of smallness in comparison with the first summands, and the equations themselves from finite-difference ones turn into differential ones.

The function $U_T^i(x)$ - the distribution of the negative potential of the pipe surface of each i-th RMS is the solution to the system of differential equations:

$$\frac{dU_T^i(x)}{dx} + R_{fl} i = 0 , \qquad (1.6)$$

$$\frac{di}{dx} + \frac{U_T^i(x)}{R_{ins}} = 0 , \qquad (1.7)$$

i - the distribution function of the current strength values.

General solution of the system of differential equations:

$$U_T^i(x) = Ae^{x \cdot \sqrt{\frac{R_{fl}}{R_{ins}}}} + Be^{x \cdot \sqrt{\frac{R_{fl}}{R_{ins}}}} , \qquad (1.8)$$

$$i = -\frac{1}{\sqrt{R_{fl} \cdot R_{ins}}} (Ae^{x \cdot \sqrt{\frac{R_{fl}}{R_{ins}}}} - Be^{-x \cdot \sqrt{\frac{R_{fl}}{R_{ins}}}}) , \qquad (1.9)$$

where the attenuation coefficient α is determined by the expression $\alpha = \sqrt{\frac{R_{fl}}{R_{ins}}}$, and the constants A and B are determined for each section of continuous current change from the conditions at the boundaries of the same section.

The values of the positive soil potential created $U_{soil}^i(x)$ by the electric field of the anode grounding of the i-th RMS is determined by the expression [10]:

$$U_{soil}^i(x) = \frac{I_i \rho_{soil}}{2\pi(b_i - a_i)} \cdot \ln\left(\frac{(x - a_i) + \sqrt{(x - a_i)^2 + y_i^A}}{(x - b_i) + \sqrt{(x - b_i)^2 + y_i^A}} \right) , \qquad (1.10)$$

where are the a_i , b_i , y_i^A coordinates of the location of the extended anode grounding of the i-th RMS.

The distribution function of the "pipe-ground" $U_{P-G}(x)$ potential for n RMS is as follows:

$$U_{P-G}(x) = \sum_{i=1}^{n} U_P^i(x) - \sum_{i=1}^{n} U_{soil}^i(x). \tag{1.11}$$

The main random variables affecting the value of the protective potential "pipe-ground" are: the actual state of the pipeline insulation coating at point x at time t and the corresponding transition resistance of the insulation coating, as well as the actual value of soil resistance along the pipeline route, depending on soil moisture , its composition, density, temperature, etc.

Let the probability space $\langle \Omega, F, P \rangle$, where Ω is the space of elementary outcomes, is the F – σ algebra of subsets Ω , P –and is the probability measure on F .Let us define the parameters R_{ins} and ρ_{soil} as random variables in space $\langle \Omega, F, P \rangle$: $\rho_{soil} = \rho_{soil}(\omega, t)$, $R_{ins} = R_{ins}(\omega, t)$ where $\omega \in \Omega$.

As discussed earlier, the pipe-to-ground potential at point x is the sum of the potentials of each RMS and is the difference between the negative pipe potential and the positive soil potential.The negative potential of the pipe depends on the random value of the insulation resistance $U_P^i(x) = U_P^i(x, R_{ins}(\omega, t))$ .The positive soil potential depends on a random value of the soil resistivity $U_{soil}^i(x) = U_{soil}^i(x, \rho_{soil}(\omega, t))$ so the pipe-to-ground potential is also a random value:

$$U_{P-G}(x, t, \omega) = \sum_{i=1}^{n} U_P^i(x, R_{из}(\omega, t)) - \sum_{i=1}^{n} U_{soil}^i(x, \rho_{гр}(\omega, t))$$

CONCLUSION

At present, the greatest attention is paid to the problems of formalizing the planning processes and effective management of the operating modes of the ECP MT system in order to create various telemetric, information-analytical and automated systems.

To create such systems, mathematical models for describing the ECP technological process are required. The paper proposes stochastic models and methods for solving the problem of operational planning of the operating modes of the SCZ of pipelines in conditions of incomplete information when solving the problem of minimizing the cost of operating the ECP system.

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