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INFORMATION TECHNOLOGY FOR RISK-BASED PIPELINE RESOURCE ASSESSMENT

ІНФОРМАЦІЙНА ТЕХНОЛОГІЯ ОЦІНЮВАННЯ ЗМІНИ СТАНУ ДЕФЕКТІВ У МАГІСТРАЛЬНИХ ТРУБОПРОВОДАХ З УРАХУВАННЯМ РИЗИКУ

Summary. *A mathematical model for estimating the resource and efficiency of underground metal pipelines (UMP) based on the use of information technology, quality engineering, and fracture mechanics approaches has been improved. The basis of information technology is the principles of UMP monitoring and the cathodic protection (CP) system. A conceptual model of information technology has been developed to increase the effectiveness of UMP and reduce relevant risks based on UMP and monitoring data, taking into account changes in the state of external surface layers, cracks, and pitting. To optimize information flows in the monitoring system of the gas transportation system, which includes the cathodic protection system, and to improve the anti-corrosion protection system of underground pipelines, the quality function was used, taking into account the inverse relationship and the principles of quality engineering.*

Key words: *underground pipeline, surface layer, risks, efficiency, resource, cracks, pitting, conceptual model, information technology, quality criterion.*

Анотація. *Удосконалено математичну модель для оцінювання зміни стану дефектів та ефективності підземних металевих трубопроводів (ПМТ) на основі використання підходів інформаційної технології, інженерії якості, механіки руйнування. В основі інформаційної технології принципи моніторингу ПМТ і системи катодного захисту (КЗ). Проектована інформаційна технологія полягає у розробці кількох компонент: математична модель корозіометрії, що розглядає контроль якості підземних трубопроводів у контексті виявлення поверхневих дефектів (тріщин, пітингів), моделювання процесу з точки зору системи управління якістю, моделювання процесів з точки зору організаційних структур (персонал, інжиніринг якості, забезпечення безпеки експлуатації технологічного процесу ГТС), моделі дефектів і методи їх розпізнавання, а також критерії міцності відповідних елементів конструкцій з дефектами (тріщини, виїмки). В основі інформаційної технології удосконалені оптимізаційні моделі корозіометрії, системи управління якістю, включаючи якісні та кількісні параметри. Для оптимізації інформаційних потоків в системі моніторингу ПМТ і покращення системи протикорозійного захисту підземних трубопроводів використано функціонал якості з урахуванням оберненого зв'язку і принципів інженерії якості. В контексті проектування інформаційної системи та інженерії якості запропоновані способи підвищення ефективності підземних металевих трубопроводів (ПМТ) на основі дослідження множини інформативних параметрів контролю технічного стану та режиму роботи газопровідних систем з урахуванням катодного захисту (КЗ) та врахування потенційних ризиків. Моніторинг і аналітика* *результатів за допомогою інформаційної технології дозволить оптимізувати параметри системи та оцінити ресурс функціонування ПМТ. Розроблено концептуальну модель інформаційної технології щодо підвищення ефективності ПМТ та зменшення відповідних ризиків на основі даних моніторингу ПМТ та КЗ з урахуванням зміни стану зовнішніх поверхневих шарів, тріщин, пітингів.*

Ключові слова: *підземний трубопровід, поверхневий шар, ризики, ефективність, ресурс, тріщини, пітинги, концептуальна модель, інформаційна технологія, критерій якості.*

Introduction. The problem of obtaining high-quality information about the state of pipeline structures is important for technical diagnostics and environmental safety of gas transportation systems (GTS). After all, during the destruction of underground main pipelines and the instantaneous release of energy, mechanical damage to the natural landscape and relief occurs, as well as a violation of the integrity of the soil and plant cover [1]. During the ignition of gas, it is possible to damage territories with a radius of up to 550 m from the center of the accident, and fragments of the pipeline after the explosion can spread up to 480 m [1].

In this regard, it is advisable to use modern monitoring methods in combination with information technology (IT) and computer modeling, as well as taking into account the methods of quality engineering and the mechanics of the destruction of solid bodies, for the control of underground metal pipelines (UMP).

Analysis of recent research and publications. The article [2] discusses the specifics of modeling the quality of complex systems using the quality functional.

To improve the procedure for diagnosing this type of system with the help of information and measurement technology, the diagnostic weight of signs and the diagnostic value of examinations are introduced, which will contribute to improving the quality of research [2].

In [3], the methodology for diagnosing the conditions of complex industrial objects is outlined, which can be used during the creation of control tools and devices, in particular, for underground metal pipelines (UMP).

The life cycle processes (LC) related to the quality assurance of computer systems (CS) are considered – the processes of verification, validation, testing, measurements, quality assurance, risk and quality management in the field of research in the field of quality engineering [4].

The directions of the development of quality engineering of CS, which are developed in a new paradigm of programming – generative programming (GP) [4]. Current problems of ensuring the quality of families of systems, which form the basis for building individual CSs – members of families – from reused components, are characterized. The tasks of family quality engineering and approaches to their solution are formulated, in particular, the tasks of verification, testing, modeling and evaluation of the quality of CS in the new paradigm [4].

An overview of the main technical-analytical transformations of information useful for monitoring the state of pitting resistance of metal structures with the participation of pitting depth restoration data was carried out [5]. Based on the results of monitoring the state of metal pitting resistance, the practical result of pitting depth restoration on the metal surface is presented [5]. A description of the interface and features of working with the developed expert system for assessing the risk of destruction of structural elements of the thermal power system is given [6]. When determining the permissible sizes of defects, the planned service life of pipeline elements is taken into account [6].

The purpose of this work is the use of information technologies and quality engineering approaches to improve the efficiency of underground metal pipelines (UMP) based on the study of a set of informative control parameters of both the technical condition and the mode of operation of gas pipeline systems, taking into account cathodic protection (CP) and risks.

Application of resource assessment with risks in information technology. The basis of UMP monitoring is the control of corrosion defects [7]. The pipeline corrosion monitoring system (PCMS) is designed to determine the places of damage to the protective coating, measure the potentials (corrosion, polarization, protective, transverse and longitudinal gradients) of the pipeline, the corrosion activity of the soil (the corrosion rate of the metal of the pipeline at different levels of its occurrence) and the rate of residual corrosion pipeline metal in the defects of the protective coating [7].

The criterion for damage to the protective coating of the pipeline is the polarization potential E_P and its deviation ΔE_P, which is related to cathodic protection and is determined by the relevant regulatory documents [7]. Measurement E_P is performing with the CP system turned off on the controlled section of the pipe by the method of removing a non-polarizing reference electrode.

In the software of the monitoring system (MS) and the UMP cathodic protection system, we will install a program for automatic calculation of the corrosion activity of the soil (that is, the corrosion current density i_K) according to the formula [6]:

$$i_K = \frac{2B\Delta I}{S\Delta E}, \text{ mm/year, (1 mm/year = 0,8616 A/m}^2\text{)}, \quad (1)$$

where B – constant of the method (for pipe steel is 332); S – the surface area of one electrode of the sensor for estimating the corrosion rate (CR), ΔI – the measured value of the electric current, A; ΔE – the potential difference set between the working electrodes of the CR sensor (10 mV).

After determining the corrosion activity of the soil i_K (current density) can be calculate the speed i_D (current density) of residual corrosion of the metal of the pipeline in the defect of the protective coating according to the formula [7]:

$$i_D = i_K \cdot 10^{V_b}; \quad V_b = (E_{cor} - E_P) / b_a, \tag{2}$$

where E_{cor} – corrosion potential of pipeline metal, V; E_P – polarization potential at the measurement point, V; b_a – the slope of the anodic polarization curve in the Tafel equation, V.

The Tafel equation relates the overvoltage to the electrode response η dissolution of metal (steel) with corrosive (anode) current density i_A [7]:

$$\eta = a + b \lg \frac{i_A}{i_N}, \; a = \frac{2{,}3RT}{(1-\alpha)nF} \lg \frac{i_A}{i_N}, \; b = \frac{2{,}3RT}{(1-\alpha)nF}, \; i_A = i_0 \cdot \exp\left[\frac{(1-\alpha)nF}{RT}\eta\right]. \tag{3}$$

Here i_N = 1 A/м^2 – a normalization factor that provides a dimensionless ratio under the logarithm sign; n – the number of electrons involved in the electrode reaction of metal dissolution; T – temperature; R – universal gas constant; F = 96485 C·mol – Faraday constant; α – transfer coefficient; i_0 = exchange current (which meets the condition $|i_A|=|i_C|=i_0$; i_C – cathode current).

The corrosion process is most intense at the top of the crack, and therefore, for a more detailed analysis of the anodic dissolution of the metal, it is advisable to take into account the ratio introduced in Keshe's monograph [9] and summarized in the work [10]:

$$i_A = \frac{\alpha \cdot \chi \cdot \Delta\psi_{ak}}{\delta \cdot \ln(c/\delta)} \cdot \left(1 + \beta_W \cdot \left(\frac{W_{PL} - W_{PL0}}{W_{PL0}}\right)^S\right), \tag{4}$$

where α – the corner at the top of the surface defect (cracks, pitting); χ – electrical conductivity of the electrolyte (in particular, soil); $\Delta\psi_{ak}$ – ohmic change in electric potential between the anodic (A) and cathodic (C) sections; c, δ – effective depth and crack opening, respectively; β_W, S – empirical constants; W_{PL} – surface energy of plastic deformation (SEPD) under the condition of a stressed state $\sigma/\sigma_T=1\div1{,}3$ in the range of plastic deformations; σ – mechanical stress; σ_T – yield strength; W_{PL0} – SEPD provided there is no external mechanical load. Ratio (4) is written for the top of the crack, that is, the anode A. The side surfaces of the defect are covered with weakly conductive oxides (passive films) and are the cathode C.

The ratio (1)–(4) is the basis of the improved model of corrosiometry (Fig. 1) and the corresponding information technology compared to [10].

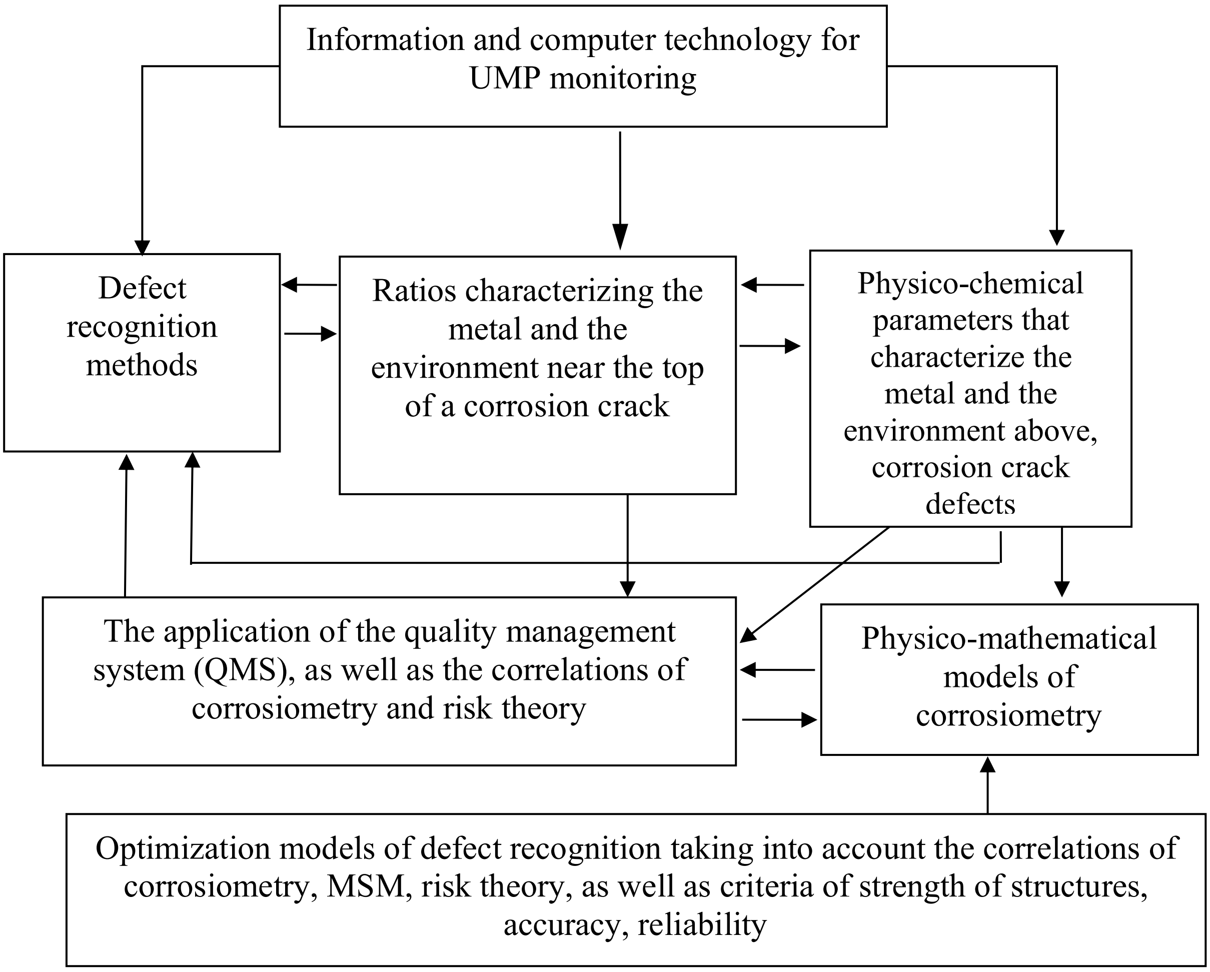

Fig. 1. Structural diagram of information and computer technology taking into account corrosion processes near the top of the crack, quality management system (QMS), risks

The information technology (Fig. 1) of the UMP monitoring system combines 4 types of models:

– mathematical model of corrosiometry considering the quality control of underground pipelines in the context of detecting surface defects (cracks, pitting) [1; 2; 7; 10; 11];

– process modeling from the point of view of the quality management system (QMS) [12];

– modeling processes from the point of view of organizational structures (personnel, quality engineering, ensuring the operational safety of the technological process of the GTS) [3; 4; 13];

– models of defects and methods of their recognition, as well as strength criteria of the corresponding elements of structures with defects (cracks, pitting) [15–17].

The next step is to consider the integral indicator of the effectiveness of the PMT monitoring system, similarly to [13] with the addition of parameters of the quality management system (QMS) [12]:

$$E_F = f(F(R), F(D), F(Q), F(I_t, P_t)) \Rightarrow opt. \qquad (5)$$

Here $F(R)$ – efficiency of resource use from the point of view of the corrosiometry model; $F(D)$ – the effectiveness of the structural divisions of the GTS; $F(Q)$ – efficiency as a result of the functioning of the QMS; $F(I_t, P_t)$ – the function of productivity, as well as the efficiency of the activities of employees (staff); I_t – index of creative potential, qualification and loyalty of employees; P_t – a model of the choice of behavior of employees (staff), including qualitative and quantitative parameters P_{ti}. ($i = 1, 2, \ldots n_P$; n_P – the total number of parameters of the corresponding model).

To optimize the method of recognizing defects, as well as information flows $P_k(X_i)$ in the UMP monitoring system and improvement of the anti-corrosion protection system of underground pipelines, we will use the quality functional, taking into account the inverse relationship, similarly to [14]:

$$J(P_k(X_i), FB(X_i)) = \int_{t_0}^{t_k} f(\bar{y}, \bar{u}, \bar{\zeta})dt \Rightarrow opt\,, \qquad (6)$$

where $\bar{y}$ – vector of given influences ($y_j(t)$ – components of the vector, j = 1,2,…,n); $\bar{u}$ – control vector; $\bar{\zeta}$ – vector of uncertain disturbances; [t_0, t_k] – ithe time interval in which the process is considered (formation of optimal values of information and financial flows $P_k(X_i)$; k=1,2,…,m; i=1,2,…,m_p; m – the total number of information and financial flows related to this system (GTS); m_p –

total number of parameters); $f(\bar{y},\bar{u},\bar{\zeta})$ – a function that displays a quality indicator; $FB(X_i)$ – a function that characterizes the inverse relationship (*Feed-back*) between flows P_k and the UMP environment, taking into account the opinions of experts. Here is a symbol *opt* corresponds to the optimality condition of the functional.

It is appropriate to consider that the reverse relationship $FB(X_i)$ associated with risks and parameters that characterize the quality, reliability and accuracy of the parameters that will be obtained on the basis of the approaches proposed in this paper. To optimize risks, we take into account the following factors [14, 15]: quality and reliability, information capacity and risk factors associated with software.

At the current rate of development of the software industry, it is important to form a problem area (PA), improve the quality of software systems (SS), build a SS in a new paradigm of generative programming (GP) from a set of various types of reusable software components, as well as constant accumulation, generalization and use knowledge about PA and prospects for their evolution [4]. SS engineering is equated with SS family engineering [4].

The search for ways to solve quality engineering problems concerns the UMP monitoring system (Figure 1). These are the following problems [4]:

1) modeling the quality of the SS family and evaluating the quality of the generated artifacts at each stage of the PA engineering and application engineering.

2) selection of components that best meet the requirements for the target SS.

3) verification of PA assets. The problem is the lack of methods for verifying the compliance of selected (developed) assets with the needs of the PA, in particular, proving the correctness of models, components, architectural compositions of components.

4) testing of new generation components. The problem lies in the need to

adapt the existing methods of online (operational) testing of selected components for SS generation, in particular, web components.

5) development of testing tools. It seems that testing tools for SS components and their compositions, as a specific type of SS in PA testing, could themselves form families, which would facilitate their adaptation to the software architecture of the IDE environment in which the target SS is developed.

6) certification of components – approval of their compliance with generally accepted standards, as well as adequacy of a given set of requirements. The problem is that the initial code of the selected components (Commercial Off-The-Shelf systems COTS products or products from the Internet) is not available for analysis and verification by known methods. It is necessary to combine different strategies of certification testing, including testing not only by developers, but also by suppliers and consumers of these components.

7) definition of an operational software architecture that will not contradict the quality requirements of the SS. The problem is that the software architecture of the SS, which is built from the family architecture by composition, must be formed taking into account not only the functional requirements for the SS, but also the quality requirements.

8) risk management during the entire life cycle (LC) of QMS generation. The problem is the need to analyze trade-offs when choosing one or another architectural composition, SS generation strategy, testing and quality assessment. Appropriate problem solving is related to the definition of the taxonomy of risks and the regular assessment of risks at each stage of the generation of SS.

Conclusions. A structural diagram (Fig. 1) of a conceptual model of information and computer technology for the protection of underground pipelines has been developed, taking into account the methods of recognizing defects, corrosion processes near the top of the crack, risks, quality criteria and strength of structural elements. The basis of information technology is improved optimization models of corrosiometry, quality management (QMS), including qualitative and quantitative parameters. To optimize information flows in the UMP monitoring system and improve the system of anti-corrosion protection of underground pipelines, the quality function was used, taking into account the inverse relationship and the principles of quality engineering.

Prospect. It is advisable to focus the proposed structural scheme of information and computer technology on the optimization of oil and gas transport systems during unstable and crisis situations.

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