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Wójcik W., Prof., Lublin, Poland
Yuzevych V., Prof., Lviv, Ukraine

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Computer Electronics

Information Technology of Surveys and Diagnostics of Underground Pipelines

Roman Dzhala
Dept. of Electrophysical Methods of Non-Destructive Testing
Karpenko Physico-Mechanical Institute of the NASU
Lviv, Ukraine
dzhala@ipm.lviv.ua

Vasyl' Dzhala
Dept. of Electrophysical Methods of Non-Destructive Testing
Karpenko Physico-Mechanical Institute of the NASU
Lviv, Ukraine
vjoe@ipm.lviv.ua

Bohdan Horon
Dept. of Electrophysical Methods of Non-Destructive Testing
Karpenko Physico-Mechanical Institute of the NASU
Lviv, Ukraine
goronbohdan@gmail.com

Oleh Senyuk
Dept. of Electrophysical Methods of Non-Destructive Testing
Karpenko Physico-Mechanical Institute of the NASU
Lviv, Ukraine
ssenya@gmail.com

Bohdan Verbenets'
Dept. of Electrophysical Methods of Non-Destructive Testing
Karpenko Physico-Mechanical Institute of the NASU
Lviv, Ukraine
bohdan_v@meta.ua

***Abstract*—The problems of inspections, nondestructive testing, and diagnostics of underground pipelines from the standpoint of the structure and functioning of modern cyber-physical systems are discussed. Method and apparatus for contactless measurement of currents with memory and automatic computer processing of results improve efficiency and information of testing to ensure the reliability and extension of trouble-free operation of pipelines.**

***Keywords*—diagnostics, underground pipelines, contactless observation, measuring testing, cyber-physical systems, information technologies.**

I. Introduction

Underground pipelines (UP) transport gas, oil, water, and products of the chemical industry. In the world, there are more than 2 million km of pipelines. The damage to the pipelines causes losses and interruptions in the supply of transportable products, leading to accidents and catastrophes with severe environmental consequences.

For reliable and trouble-free operation of these important and expensive underground communications, periodic diagnostic examinations are required (as the characteristics of the materials and conditions on the roads change over time) and appropriate preventive maintenance and corrosion protection.

II. The State of the Problem

A. Analysis of the state of the problem

Modern diagnostics of pipelines covers a number of methods and develops in various areas of research and development topics [1-6], including:

- estimation of residual resource, strength of pipeline materials;
- safety, monitoring, diagnostics;
- radiation control methods;
- ultrasound diagnostics; acoustic emission control, vibration diagnostics;
- magnetic and electromagnetic diagnostics;
- optical, thermal and ecological diagnostics;
- mobile laboratories, equipment, leak search;
- personnel training, standards, metrology.

In the practice of surveying the state of corrosion of underground metal pipelines, mainly contact methods of measurements from the surface of the earth, which are relatively easy to use and essentially do not require sophisticated equipment, are used. However, their essential disadvantages [1] are:

- the complexity of providing reliable contacts with the UP and the soil, at transitions under rivers, in wetlands and in vegetation thickets on the route;
- the unreliability of contacts of the electrodes with the soil with high resistance to the surface of the earth (dry soils, asphalt, etc.);
- limited range of activities (local character of control);
- dependence of the signal on the ground resistance and depth of the pipe; the need to pre-specify the location of the pipeline.

Intracellular defectoscopy makes it possible to detect defects in the metal wall of the pipe but does not provide information on the state of corrosion protection of UP.

Therefore, the development and use of contactless methods and means of UP examinations are relevant [3, 7 – 9].

Contactless methods of surveys on mobility, productivity and informativity have significant advantages over traditional contact methods. But they needed special means of measurement and therefore were not widely used.

Karpenko Physico-mechanical Institute of the National Academy of Sciences of Ukraine conducted a complex of research of the electromagnetic field and UP signals, created algorithms, means of measuring and processing information about the state of anti-corrosion protection (ACP) of UP [1, 3, 7 – 9].

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B. Purpose and tasks

In this article, the complex problem of inspection, control of parameters and diagnostics of the state of underground pipelines [1, 7–9] is considered from the standpoint of the structure and functioning of modern cyber-physical systems [3]. The main focus is on controlling the corrosion of the UP, which is crucial for ensuring reliability and prolonging their non-hazardous operation.

According to modern requirements, periodic non-destructive monitoring and continuous monitoring of certain indicators of the technical condition of the control object are foreseen. This requires quite convenient methods and tools for collecting, computer processing, documenting and transmitting measured information, further accumulation, storage and analysis for decision making and efficient management, prevention of damage and ensuring the reliability of the operation of pipeline systems.

III. The Basis of Information Technology of UP Examination

A. Theoretical Foundations

The interaction of an electromagnetic (EM) field with a given physical object – UP is investigated using the proposed triune mathematical model (TMM) of the EM field of an underground steel insulated pipeline [3].

This model is based on:

- solving boundary value problems of electrodynamics,
- the theory of electric circuits with distributed parameters,
- the theory of the field distribution of bulk conductors currents.

TMM provides an opportunity to effectively investigate the electromagnetic phenomena associated with the corrosion of the UP, facilitates the identification and analysis of informative features of the field and the development of ACP methods and systems, and is the theoretical basis for the EM information-measuring system.

The interrelation between geometrical and electrical parameters of UP (insulation, environment) and characteristics of its EM field is investigated. The necessary parameters of the measuring converters are determined, algorithms of signal processing and determination of currents, resistances, electric potentials for the estimation of the state of the ACP UP have been constructed.

B. Development of contactless methods and equipment

In order to increase the efficiency of information gathering along the UP routes, the method of contactless currents measurement (CCM) has been developed, the possibilities of its use for diagnostic examinations of UP have been explored. Among the differential CCM are gradient (radial), invariant and parallax (azimuthal), shown in Fig. 1. Figure 1 shows the induction of magnetic field receivers. By their signals, we quickly determine the location of the UP, measure the distance to its axis (depth of occurrence) and the strength of the current flowing along the pipeline.

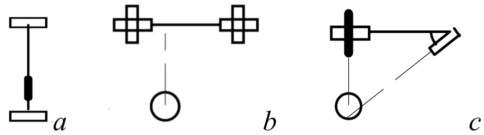

Fig. 1. Means of contactless measurements of the pipeline depth and current: *a* – radial (gradient); *b* – invariant; *c* – azimuthal (parallax).

New methods and devices of CCM are offered. The equipment of the parallax and gradient types is developed that provides the determination of the location, direction and depth of the pipelines and conductive communications and the measurement of current without connecting to the pipeline and the earth [3, 8, 9]. The measurement process is carried out automatically; the operation of the equipment is controlled by a microprocessor under a specially designed program.

The equipment is equipped with electronic memory, which provides automatic fixing of measurements. In order to expand the functionality of the equipment, parallax type additionally equipped with a voltmeter for measuring the potential of cathode protection.

According to the results of contactless measurements of currents directly on the track, the operator makes the first conclusions about the state of the ACP, controls the depth of the UP, checks the presence of cathode corrosion protection current, detects places of abnormally high current consumption.

The density of current consumption in each section of the UP with a length l_n is determined by the CCM at the beginning of J_{n-1} and the end of J_n of each section by the formula

$$j_n = (J_n - J_{n-1}) / s_n, \quad \text{A/m}^2, \qquad (1)$$

where s_n is the surface of the UP in this section.

The relative current consumption $Rel\ J_n$ for each UP section with length l_n is determined by

$$Rel\ J_n = 2\,(J_n - J_{n-1}) / (J_n + J_{n-1})\, l_n, \quad \text{m}^{-1}. \qquad (2)$$

This value in the first approximation is equal to the current attenuation along the route and makes it possible to compare the quality of insulation at different UP sections. In contrast to the known definition of attenuation through a logarithm, formula (1) is quite simple. Therefore, the calculation for (2) is performed by the microprocessor of the CCM apparatus. This gives an opportunity to quickly evaluate the quality of insulation at different sections of UP.

A new criterion for detecting UP sections with unsatisfactory insulation at critical current costs was proposed and verified in the field conditions [3, 9]. These critical relative current charges J_{cr} depend on the current frequency f and the specific conductivity of the soil Rog:

$$Rel\ J_{cr} = 0{,}2\,(f / Rog)^{1/2}, \quad \% / \text{m}. \qquad (3)$$

If the relative current consumption (2) exceeds its critical value (3): $Rel\ J_n > Rel\ J_{cr}$, then the insulation on the n-section of the UP will be unsatisfactory.

C. Development of potentials measurements

Polarization potential (PP) is considered as the main criterion for protection against corrosion of metal constructions in a conductive medium [1, 3, 9].

The measured high-ohm voltmeter potential between a comparison relative electrode (RE) and a metal of a protective design includes, in addition to the polarization component, an ohmic drop in the *IR* voltage due to the passage of the cathode current *I* through to the effective resistance *R* between the comparison electrode and the metal of the structure [1, 9]. To overcome the disadvantages of known methods of measurement of PP (compensating, relaxation, stationary auxiliary electrode), [3, 9] a new method for measuring the PP (MPP) with the removal of an ohmic component by measuring constant and alternating electric voltages is proposed.

By measurements of the constant U_{me} and the V_{me} variable voltage between the metal of the control object (CO) and the RE and the corresponding U_{ee} and V_{ee} voltages between the RE and additional electrode (AE) in the soil (as shown in Fig. 2), the polarization potential is determined by

$$U_p = U_{me} - V_{me}\, U_{ee} / V_{ee} \quad (4)$$

To implement the proposed method, four-channel equipment of MPP type [3, 9] with microprocessor and memory was developed.

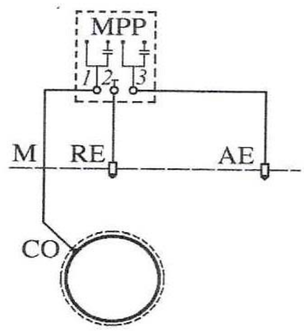

Fig. 2. Contacts of the MPP device with the object of control and the environment for measuring the polarization potential.

The measurement process is carried out automatically. The work of the equipment is controlled by a microprocessor under a specially designed program. Reading of the measured voltages and calculating the polarization potential is carried out by the formula (4).

The coordinates of the measurement locations are determined by the GPS module, which greatly simplifies the documentation procedure. It is possible to record measurements in memory and view the results on the digital display. Data transfer from the device via the interface to the computer has been implemented for further processing and documentation.

The natural tests on the tracks of the underground main pipelines confirmed the suitability of runway to find damage to the insulation of the UP as the difference in potentials (the gradient method) and on the alternating current according to the known Pearson method, as well as to determine the polarization potential of the metal structures in the conductive medium according to the Dzhala method [3, 9].

In addition, the MPP in the complex with contactless measurements of the currents makes it possible to determine the distribution of the density of the constant component of the cathode protection installation current and the resistance of the insulation at different sections of the underground pipelines.

D. Improvement of pipelines survey

The measured data arrays accumulated on the track are transferred from the portable equipment to the computer for processing and documenting through the interface. The criteria and developed algorithms for extracting incorrect measurements (failures) are selected [3]. The data tables and their graphical representations are formed by special program [3, 9].

The methods for determining the parameters of the insulating coating and the electrochemical protection against corrosion of steel UP have been developed. The technology of contactless integrale, differential and local inspection of the ACP UP by CCM with the rational use of contact electrometry [1, 3, 9] has been proposed.

Methods of determination of the distribution along the path of ACP parameters of UP are developed. For the first time, it was proposed to determine the density of the constant component of the cathodic protection current on the sections of the UP by the contactless measurements of the alternating component of the pulsating current of the cathodic protection installation:

$$i_n = j_n / k_n, \quad \text{A/m}^2, \quad (5)$$

where $k_n = (V_{ee} / U_{ee})_n$, – the harmonic coefficient of the alternating component of the current at the given *n*-section of the UP.

Using measurements of currents and potentials, the transition resistance of the "pipe-earth" on the n-section of the UP is determined by:

$$R_{mg} = U_{me} / i_n \, . \quad (6)$$

By the above measurements of currents and potentials, and the depth *h* of occurrence and diameter of the pipeline, we determine the specific resistance of the ground and the voltage drop U_g in the soil over the UP [3, 9]. This makes it possible to determine the voltage on the insulating layer $U_i = U_{me} - U_g - U_p$ and calculate the value of the resistivity of the insulation covering on the UP *n*-section:

$$R_i = U_i / i_n \, . \quad (7)$$

We develop methods and means to increase the noise immunity of the examinations and detect defects in the UP metal.

Detailed local investigations with the possible subsequent excavation of the UP (for monitoring the pipe`s body state in the shells) are recommended to be carried out in the areas of abnormally high cathodic protection current losses [1, 3, 9].

Thus, using CCM and MPP, we have for each *n*-section of the UP the array of measured data:

$$J_n ,\ h_n ,\ l_n ,$$
$$U_{m,},\ \ V_{m,},\ \ U_{ee} .\ \ V_{ee} , \qquad (8)$$

After processing them, extracting errors, filtering, using the formulas given above, we obtain an array of state parameters - knowledge about the ACP UP:

$$j_n,\quad Rel\ J_n,$$
$$U_{me},\quad U_p,\quad U_i,\quad U_R,$$
$$k_n ,\quad i_n ,\quad R_{mg} ,\quad R_i ,\quad R_p . \qquad (9)$$

E. Results of practical use

According to the results of the operative field surveys, the compliance of the controlled parameters with their normative standard values is first determined. Then they make conclusions about the possibilities and modes of further operation of the UP, or the needs and volumes of preventive adjustment of active electrochemical protection, or selective or general repair of the protective insulation cover of the UP, or major overhaul of the pipeline. Additional UP surveys may be required with the use of other methods of measuring control.

According to the modern information technology, the results of field measurements on the pipelines' routes, their processing and the conclusions of diagnostic surveys are entered in the electronic passport of the pipeline. This passport contains all the information about each object, from its design and construction, modes of use, inspections, repairs and reconstruction, maintenance.

The analysis and processing of multifaceted information recorded in an electronic passport can be performed using neural networks [10, 11]. It will allow to make prompt decisions for optimal management of technical parameters for the purpose of reliable and economically justified functioning of pipeline transport.

IV. Conclusion

New information technology of diagnostic examinations of underground pipelines on the basis of contactless measurement of currents is developed.

For the first time, it was possible to expedite the detection of abnormally high expenses of current in the area of the cathodic protection installation (CPI) of the UP. In these places there is the worst state of UP insulation, so they need to first of all control the state of electrochemical corrosion protection (to measure the polarization potential PP). If, at the places of the highest relative expenses of current, the PP meets the regulatory requirements, then the PP will be satisfactory throughout the area of the CPI. Then contact measurements of potentials along the entire length of the CPI zone may not be performed. These significantly reduces the number of field measurements for the testing and diagnostics of the ACP of the UP.

Integration of this technology (with the created means of technical and methodological support) into the overall system of anti-corrosion protection increases the efficiency and informativeness of the surveys, gives the opportunity to switch from regular maintenance to maintenance or repair on a technical condition to prevent damage. It increase reliability and extend the useful life of expensive and important underground pipelines and related structures.

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