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TABLE OF CONTENTS

Information Technologies

Discrete-Time Control of Capacitated Multi-Channel Distribution Systems with Batch Replenishments <i>Przemysław Ignaciuk</i>	2
Detection of Subsurface Defects in Composite Panels Using Dynamic Speckle Patterns <i>Leonid Muravsky, Oleksandr Kuts, Georgiy Gaskevych, Olga Suriadova</i>	7
About Improving the Measuring Distances Accuracy Based on Correlation Analysis of Stereo Images <i>Vladimir Kozlov, Waldemar Wojcik, Natalia Zgirovskaya</i>	11
Biometric Identification System with Ateb-Gabor Filtering <i>Mariya Nazarkevych, Nataliia Lotoshynska, Vasyl Brytkovskyi, Serhii Dmytruk, Vasyl Dordiak, Iryna Pikh</i>	15
Comparison of the Effectiveness of Fingerprint Skeletal Methods <i>Mariya Nazarkevych, Vasyl Dordiak, Vasyl Brytkovskyi, Khrystyna Pelekh, Iryna Pikh, Yaroslav Voznyi</i>	19
Identification of Wear Products in the Automotive Tribotechnical System Using Computer Vision Methods, Artificial Intelligence and Big Data <i>Olexiy Balitskii, Valerii Kolesnikov</i>	24
Competence-Based Hierarchical Case Base for Control of Unmanned Vehicle Teams <i>Vladimir Sherstjuk, Nataliia Kozub, Igor Sokol, Ruslan Levkivskiy</i>	28
Development and Usage of a Computer Model of Evaluating the Scenarios of Projects for the Creation of Fire Fighting Systems of Rural Communities <i>Roman Ratushny, Anatolii Tryhuba, Oleg Bashynsky, Vadym Ptashnyk</i>	34
Development of Client and Server Software for use in Mass Service Facilities <i>Orest Babych, Yurii Hutak, Arthur Yuzkiv, Oleksandr Futey</i>	40
Conciseness of Ukrainian, Russian and English: Application to Translation Studies <i>Oleg Kushnir, Oksana Dzera, Liliya Kushnir</i>	44
Computational-Measurement System “Nanoplasmonics”. Part 1: Architecture <i>Ivan Bolesta, Oleksii Kushnir, Mykhailo Bavdys, Ivan Khvyshchun, Antonina Demchuk</i>	51
Computational-Measurement System “Nanoplasmonics”. Part 2: Structure of Microservices <i>Ivan Bolesta, Oleksii Kushnir, Mykhailo Bavdys, Ivan Khvyshchun, Antonina Demchuk</i>	55
Recognition of Handwritten Images Using Multilayer Neural Networks <i>Volodymyr Bihday, Volodymyr Brygilevych, Yurii Hychka, Zinovii Liubun, Nazar Pelypets, Vasyl Rabyk</i>	59
The Expert System “Pharmacy” for Determination of Availability and Conditions of Storage of Medicinal Products <i>Serhiy Sveleba, Ivan Kunyo, Nataliya Sveleba, Ivan Karpa, Ivan Katerynchuk</i>	63

Understanding the Basics of the Model-Based Techniques for Control Engineers with Simulink and BeagleBone Black: Processor-in-the-Loop Simulation of a DC Motor Speed Control <i>Oleksiy Kuznyetsov</i>	67
Oxygen Saturation Variability: Healthy Adults <i>Gennady Chuiko, Olga Dvornik, Yevhen Darnapuk, Yaroslav Krainyk</i>	72
Sliding Mode Interval Controller for the Mobile Robot <i>Roman Voliansky, Oleksandr Sadovoi, Yuliia Sokhina, Iurii Shramko, Nina Volianska</i>	76
Solution of Filtering and Extrapolation Problems when Constructing Recovery Control in Stochastic Differential Systems <i>Oleg Mashkov, Vadym Ptashnyk, Viktor Chumakevych</i>	82
The Concept of Machine Learning and Elliptic Curves United Approach in Solving of the Factorization Problem <i>George Vostrov, Ivan Dermenzhy</i>	87
Mathematical Modeling of Complex Dynamical Systems when Changing their Structure <i>Bohdan Melnyk, Nataliya Melnyk, Zoriana Melnyk</i>	92
Fractal Analysis of Porous Structures Using a Fuzzy Logic System <i>Igor Olenych, Yurii Olenych, Andriy Kostruba, Yaroslav Pryima</i>	97
Dynamic Processes of Formation Classes of Prime Numbers in a Probabilistic Model of Mathematical Computer Proof of the Generalized Artin Hypothesis <i>George Vostrov, Roman Opiata</i>	102
Using Artificial Neural Networks to Forecast Stock Market Indices <i>Svitlana Pryima, Roman Vovk, Volodymyr Vovk</i>	108
The Lyapunov's Exponents Variation on System with Incommensurate Superstructure Under Surface Energy Field <i>Serhiy Sveleba, Ivan Katerynychuk, Ivan Kunyo, Yaroslav Shmygelsky, Ivan Karpa</i>	113
Investigation of Geoinformation Models of Water Flows in Pseudoprismatic Channels <i>Yaryna Kokovska, Petro Venherskyi</i>	117
Monitoring the Virtual Reality Influence on Cognitive Tasks Performance in Healthy Individuals <i>Andrii Cholach, Solomiya Lebid</i>	121
Performance Analysis of Messages Queue in the Different Actor System Implementation <i>Baseem A. Al-Twajre</i>	127
Contactless IoT Sensor of Liquid Level based on Impedance Method <i>Bohdan Blagitko, Yuriy Mochulskyi, Ihor Zajachuk, Micle Batiuk, Ihor Kravets, Volodymyr Bihday</i>	132
Abstraction as a Way of Uncertainty Representation in Smart Rules Engine <i>Anatolii Kargin, Tetyana Petrenko</i>	136
An Improved Facial Recognition Technique Using Scale and Rotation Invariant Statistical Moments <i>Yaser Daanial Khan</i>	142
On Intelligent Decision Making in Multiagent Systems in Conditions of Uncertainty <i>Dmytro Chumachenko, Ievgen Menailov, Kseniia Bazilevych, Tetyana Chumachenko</i>	150
Neural Element of Parallel-Stream Type with Preliminary Formation of Group Partial Products <i>Ivan Tsmots, Vasyl Rabyk, Oleksa Skorokhoda, Taras Teslyuk</i>	154

On the Development of Object Detector Based on Capsule Neural Networks <i>Oleh Sinkevych, Daniil Berezhansky, Zenyk Matchyshyn</i>	159
Bitcoin Price Predictive Modeling Using Expert Correction <i>Bohdan Pavlyshenko</i>	163
Method of Neural Network Training with Integer Weights <i>Oleksandr Karpin, Vasyl Mandziy, Zinovii Liubun, Vasyl Rabyk</i>	168
Adaptive Iterative Pruning for Accelerating Deep Neural Networks <i>Yuri Gordienko, Yuriy Kochura, Vlad Taran, Nikita Gordienko, Andrii Bugaiiov, Sergii Stirenko</i>	173
Normalization Modifications for Fast Self-Quotient Image Method <i>Vitalii Parubochyi, Roman Shuvar</i>	179
IoT Image Recognition System Implementation for Blind Peoples Using esp32, Mobile Phone and Convolutional Neural Network <i>Vasyl Kushnir, Bogdan Koman, Volodymyr Yuzevych</i>	183
Deep Learning for Atmospheric Cloud Image Segmentation <i>Bohdan Rusyn, Valentyna Korniy, Oleksiy Lutsyk, Rostyslav Kosarevych</i>	188
One-step Prediction of Air Pollution Control Parameters using Neural-Like Structure Based on Geometric Data Transformations <i>Oleksandra Mishchuk, Roman Tkachenko</i>	192
The Usage of Apache Spark for Collection and Analysis of Social Networking Statistics <i>Ihor Tovpinets, Roksolana Kovtko, Volodymyr Yuzevych, Andrii Prodyvus</i>	197

Computer Electronics

Prototype of Local Positioning System <i>Lyubomyr Monastyrskiy, Yaroslav Boyko, Danylo Maksymchuk</i>	202
Apparatus and Technique for Investigating the Effective Seismic Wave Velocity in the Sediment Layer Using the Refracted Wave Method <i>Yuri Datsyuk, Bogdan Kuplovskiy</i>	206
Configurable Description of FPGA-based Control System for Sensor Processing <i>Yaroslav Krainyk, Yevhen Darnapuk</i>	210
Information Technology of Surveys and Diagnostics of Underground Pipelines <i>Roman Dzhala, Vasyl' Dzhala, Bohdan Horon, Oleh Senyuk, Bohdan Verbenets'</i>	214
Specialized Device to Control Work of Executive Mechanism Using Operator's Hand Gestures <i>Oleksii Voronchuk, Halyna Klym, Roman Dunets</i>	218
Physical and Geological Factors in Modeling of the Climate Earth Changes <i>Vitaly Fourman</i>	222
Simulation of Energy Schemes and Electron Spectrum in Plane Nitride Semiconductor Nanostructures <i>Igor Boyko, Halyna Tsupryk, Iaroslav Kinakh, Yurii Stoianov</i>	227
Influence of Bi Impurity on the Electronic Structure and Photoelectric Properties of Germanium Monosulfide <i>Dmytro Bletskan, Vasyl Kabatcii</i>	232

Computer Calculation of Cation Migration Channels in Scheelite Structure <i>Volodymyr Shevchuk, Ihor Kayun</i>	238
Diffraction Analysis of Finite Cross-Section Light Beam on Grating with Normal Incidence <i>Volodymyr Fitio, Andriy Bendzyak, Iryna Yaremchuk, Yaroslav Bobitski</i>	242
Optical Properties and Band Structure of Cu ₇ SiS ₅ I Crystal <i>Dmytro Bletska, Ihor Studenyak, Vasyl Vakulchak</i>	247
Aluminum Nitride Thermal Interface for Improving Heat Performance of High-Power Electronic Devices <i>Eduard Rudenko, Ihor Korotash, Maxim Dyakin, Denis Polotsky, Mikhail Belogolovskii, Yuri Strzhemechny</i>	253
Ultra-Low Resistance in Carbon Nanostructures <i>Eduard Rudenko, Ihor Korotash, Anatolij Krakovny, Denis Polotsky, Mikhail Belogolovskii, Vitaliy Perepelytsia</i>	257
Investigating a Discrete Model of Memristive Systems <i>Kirill Ochkan, Sasan Razmkhah, Pascal Febvre, Elena Zhitlukhina, Mikhail Belogolovskii</i>	261
Synergetic Processes in Uniaxially Deformed Crystals <i>Bohdan Koman, Volodymyr Yuzevych</i>	265
Magnetodielectric Effect in a New Multiferroic Crystals of Tetraethylammonium Tetrahalogenocobaltate <i>Volodymyr Kapustianyk, Svitlana Semak, Pavlo Yonak, Bohdan Kundys, Yurii Chornii</i>	268
Birefringence of Tl ₄ HgI ₆ Crystal <i>Andriy Kashuba, Mykola Solovyov, Taras Malyi, Ihor Semkiv, Andriy Franiv</i>	272
Low Temperature Luminescence of ZnWO ₄ Crystals with Li Impurity <i>Stepan Novosad, Ludmyla Kostyk, Volodymyr Kapustianyk, Iryna Novosad, Mykola Rudko, Myron Panasyuk</i>	277
Luminescence Properties of the Tm ³⁺ -doped LiKB ₄ O ₇ Glass <i>Bohdan Padyak, Ihor Kindrat, Volodymyr Adamiv, Ihor Teslyuk</i>	280
Structure, Surface Morphology and Luminescence Properties of β-Ga ₂ O ₃ and (Y _{0.06} Ga _{0.94}) ₂ O ₃ Thin Films <i>Oleh Bordun, Bohdan Bordun, Igor Kukharskyy, Ivanna Medvid</i>	285
Effect of Preparation Conditions and Impurities on the Spectral Characteristics of Cadmium Iodide <i>Iryna Novosad, Bogdana Kalivoshka, Stepan Novosad, Andriy Vas'kiv</i>	291
The Impact of Radiation Defects on a Photosensitivity of Silicon Single Crystals <i>Serhiy Luniov, Mykola Khvyshchun, Volodymyr Maslyuk</i>	295
Method for the Formation of a Diffraction Grating on the Semiconductors Surfaces <i>Halyna Petrovska, Iryna Yaremchuk, Serhiy Malynych, Yaroslav Bobitski</i>	299
Effect of Deep Trap Levels on Green Luminescence in β-Ga ₂ O ₃ <i>Vyacheslav Vasyltsiv, Andriy Luchechko, Lyudmyla Kostyk, Bohdan Pavlyk</i>	303

Structural Properties of Polycrystalline BaGa ₂ O ₄ Ceramics Doped with Eu ³⁺ Ions <i>Yuriy Kostiv, Andriy Luchechko, Halyna Klym, Ivan Karbovnyk, Bohdan Sadovyi, Oksana Zaremba, Oleh Kravets</i>	307
Transformation of Positron Trapping Parameters Caused by Water Molecules in Voids Near Grain Boundaries in MgAl ₂ O ₄ Ceramics <i>Halyna Klym, Adam Ingram, Roman Szatanik</i>	312
Temperature and Pressure Changes of the Refractive Properties of LiNH ₄ SO ₄ Crystal in β Modification <i>Myron Rudysh, Vasyl Stadnyk, Pavlo Shchepanskyi, Ruslan Brezvin, Oleg Kushnir, Galyna Myronchuk, Igor Matviishyn</i>	316

Information Technology of Surveys and Diagnostics of Underground Pipelines

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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].

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.

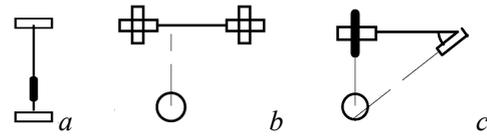


Fig. 1. Means of contactless measurements of the pipeline depth and current: *a* – radial (gradient); *b* – invariant; *c* – azimuthal (parallax).

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

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

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

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

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 :

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

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.

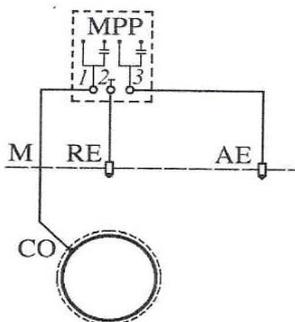


Fig. 2. Contacts of the MPP device with the object of control and the environment for measuring the polarization potential.

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:

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

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:

$$\begin{aligned} & J_n, h_n, l_n, \\ & U_m, V_m, U_{ee}, V_{ee}, \end{aligned} \quad (8)$$

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

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

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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INDEX OF AUTHORS

Adamiv V.	280	Chumakevych V.	82
Al-Twajre B.	127	Darnapuk Ye.	72, 210
Babych O.	40	Datsyuk Yu.	206
Balitskii O.	24	Demchuk A.	51, 55
Bashynsky O.	34	Dermenzhy I.	87
Batiuk M.	132	Dmytruk S.	15
Bavdys M.	51, 55	Dordiak V.	15, 19
Bazilevych K.	150	Dunets R.	218
Belogolovskii M.	253, 257, 261	Dvornik O.	72
Bendzyak A.	242	Dyakin M.	253
Berezhansky D.	159	Dzera O.	44
Bihday V.	59, 132	Dzhala R.	214
Blagitko B.	132	Dzhala V.	214
Bletskan D.	232, 247	Febvre P.	261
Bobitski Ya.	242, 299	Fitio V.	242
Bolesta I.	51, 55	Fourman V.	222
Bordun B.	285	Franiv A.	272
Bordun O.	285	Futey O.	40
Boyko I.	227	Gaskevych G.	7
Boyko Ya.	202	Gordienko N.	173
Brezvin R.	316	Gordienko Yu.	173
Brygilevych V.	59	Horon B.	214
Brytkovskyi V.	15, 19	Hutak Yu.	40
Bugaiov A.	173	Hychka Yu.	59
Cholach A.	121	Ignaciuk P.	2
Chornii Yu.	268	Ingram A.	312
Chuiko G.	72	Kabatcii V.	232
Chumachenko D.	150	Kalivoshka B.	291
Chumachenko T.	150	Kapustianyk V.	268, 277

Karbovnyk I.	307	Kunyo I.	63, 113
Kargin A.	136	Kuplovskiy B.	206
Karpa I.	63, 113	Kushnir L.	44
Karpin O.	168	Kushnir O. O.	51, 55
Kashuba A.	272	Kushnir O. S.	44, 316
Katerynychuk I.	63, 113	Kushnir V.	183
Kayun I.	238	Kuts O.	7
Khan Ya.D.	142	Kuznyetsov O.	67
Khvyshchun I.	51, 55	Lebid S.	121
Khvyshchun M.	295	Levkivskiy R.	28
Kinakh Ia.	227	Liubun Z.	59, 168
Kindrat I.	280	Lotoshynska N.	15
Klym H.	218, 307, 312	Luhechko A.	303, 307
Kochura Yu.	173	Luniov S.	295
Kokovska Ya.	117	Lutsyk O.	188
Kolesnikov V.	24	Maksymchuk D.	202
Koman B.	183, 265	Malyi T.	272
Korniy V.	188	Malynych S.	299
Korotash I.	253, 257	Mandziy V.	168
Kosarevych R.	188	Mashkov O.	82
Kostiv Yu.	307	Maslyuk V.	295
Kostruba A.	97	Matchyshyn Z.	159
Kostyk L.	277, 303	Matviishyn I.	316
Kovtko R.	197	Medvid I.	285
Kozlov V.	11	Melnyk B.	92
Kozub N.	28	Melnyk N.	92
Krainyk Ya.	72, 210	Melnyk Z.	92
Krakovny A.	257	Meniailov Ie.	150
Kravets I.	132	Mishchuk O.	192
Kravets O.	307	Mochulskiy Yu.	132
Kukharskyy I.	285	Monastyrskiy L.	202
Kundys B.	268	Muravsky L.	7

Myronchuk G.	316	Sadovyi B.	307
Nazarkevych M.	15, 19	Semak S.	268
Novosad I.	277, 291	Semkiv I.	272
Novosad S.	277, 291	Senyuk O.	214
Ochkan K.	261	Shchepanskyi P.	316
Olenych I.	97	Sherstjuk V.	28
Olenych Yu.	97	Shevchuk V.	238
Opiata R.	102	Shmygelsky Ya.	113
Padlyak B.	280	Shramko Iu.	76
Panasyuk M.	277	Shuvar R.	179
Parubochyi V.	179	Sinkevych O.	159
Pavlyk B.	303	Skorokhoda O.	154
Pavlyshenko B.	163	Sokhina Yu.	76
Pelekh Kh.	19	Sokol I.	28
Pelypets N.	59	Solovyov M.	272
Perepelytsia V.	257	Stadnyk V.	316
Petrenko T.	136	Stirenko S.	173
Petrovska H.	299	Stoianov Yu.	227
Pikh I.	15, 19	Strzhemechny Yu.	253
Polotsky D.	253, 257	Studenyak I.	247
Prodyvus A.	197	Suriadova O.	7
Pryima S.	108	Sveleba N.	63
Pryima Ya.	97	Sveleba S.	63, 113
Ptashnyk V.	34, 82	Szatanik R.	312
Rabyk V.	59, 154, 168	Taran V.	173
Ratushny R.	34	Teslyuk I.	280
Razmkhah S.	261	Teslyuk T.	154
Rudenko E.	253, 257	Tkachenko R.	192
Rudko M.	277	Tovpinets I.	197
Rudysh M.	316	Tryhuba A.	34
Rusyn B.	188	Tsmots I.	154
Sadovoi O.	76	Tsupryk H.	227

Vakulchak V.	247	Voznyi Ya.	19
Vas'kiv A.	291	Wojcik W.	11
Vasyltsiv V.	303	Yaremchuk I.	242, 299
Venherskyi P.	117	Yonak P.	268
Verbenets' B.	214	Yuzevych V.	183, 197, 265
Volianska N.	76	Yuzkiv A.	40
Voliansky R.	76	Zajachuk I.	132
Voronchuk O.	218	Zaremba O.	307
Vostrov G.	87, 102	Zgirovskaya N.	11
Vovk R.	108	Zhitlukhina E.	261
Vovk V.	108		