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COMPLEX INSPECTON OF UNDERGROUND OIL-GAS PIPE-LINES

Analysis of existingcontrol methods of underground oil- gas pipe-lines state has been carried out, the necessity of new approaches and techniques development has been shown. Complex approach to the inspection of underground oil- gas pipe-lines, located in places with considerable concentration of contiguous communications has been suggested. Usage of magnetic and microphone methods for control of the sections of underground oil-gas pipe-lines of small length is described. The possibility of application the combination of two electromagnetic methods of control (amplitude and phase) for revealing and identification of insulation damage of underground oil pipe-lines in conditions of complex technological objects is suggested.

Key words: *control, underground oil- gas pipe-line, technical state, defect, electromagnetic method, magnetic method, microphone method.*

Problem set-up in general form and its connection with important scientific or practical tasks

Underground oil-gas pipe-lines are main elements of the system of energy resources transportation on the territory of Ukraine, total length of these pipe lines is tens of thousands kilometers. Recently, accident rate of oil- gas pipe-lines increased, because the operation resource of the greater part of pipe-lines has been exhausted, cathode protection does not operate efficiently and in some places it is absent. In this connection, the problem of technical state control of underground oil- gas pipe-lines is very urgent.

Analysis of the latest research and publications, allocation of unsolved parts of general problem

Nowadays numerous methods of non-distructive control are known [1, 2], these methods are applied for determination of the site of damage, measuring certain parameters of oil- gas pipe-lines. However, the important problem remains the possibility of carrying out the study of oil-gas pipe-lines sections of small length, located in the places of considerable concentration of underground communications (for instance, the area of compressor or oil-pumping stations, Fig. 1). The separate problem is faults detection in oil- gas pipelines, located under various forms of coating (asphalt, concrete, etc.).

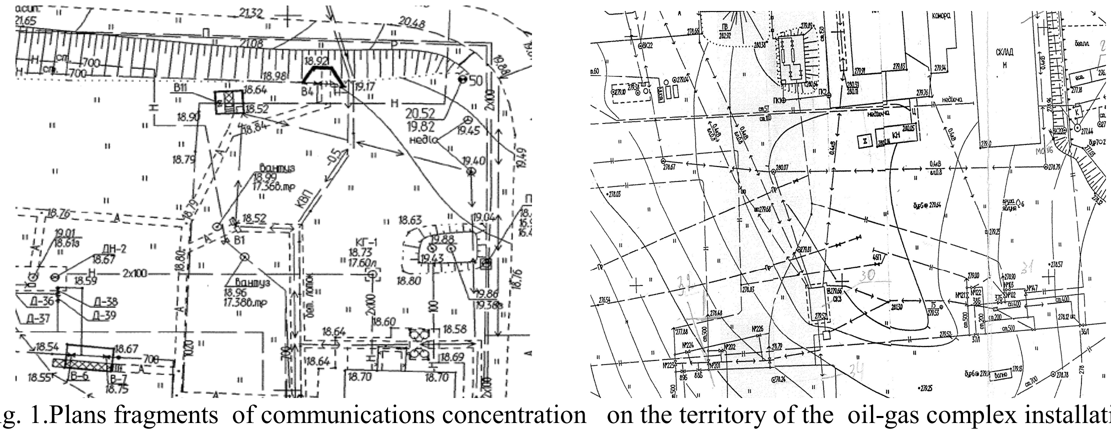

Fig. 1.Plans fragments of communications concentration on the territory of the oil-gas complex installation

It should also be noted the necessity of fault type identification because of different level of danger for safe operation of underground oil- gas-pipelines. The existing methods and techniques allow only to determine approximate places of these faults location, without the possibility of their identification. Thus, the given problem is very urgent for the process of underground oil- gas-pipelines state inspection.

Problem set-up

For investigation of technical state of such installations it is suggested to carry out complex inspections, the essence of it is the application of several methods of control based on the study of parameters of various physical origin (electromagnetic, magnetic, acoustic).

Presentation of main material of the research with substantiation of the obtained scientific results

Prior the inspection of underground oil or gas- pipeline on the territory with high concentration of underground communications, firstly, it is necessary to divide it into short sections for control (for instance, into sections, located between the compartments with stop valves). The inspection of the controlled section of the pipeline must be realized in several stages.

First, pipeline routing and the depth of its location is determined, applying conventional electromagnetic method. However, on the territory with high concentration of underground communications, the pipeline may be bending in horizontal plane under large angles (90 ^{o} and more). This results in occurring of the errors of electromagnetic methods, as single-sided concentration of magnetic lines of force in the places of pipeline bendings indicates the shift of its axis. In such case, it is expedient to apply magnetometer, by means of which, measuring the distortion of earth magnetic field, by metal pipeline, may exactly indicate the coordinates of its location.

If the pipeline is laid under reinforced concrete covering, that substantially distorts magnetic field and scatters electromagnetic signals, we suggest to apply microphone method of investigation. It consists in measuring low-frequency (sound) acoustic field of the pipeline, that is created in it by powerful magnetostrictive drill. Microphone method enables not only to reveal the axis of underground pipeline but also determine the location of the possible fault. In this case, acoustic signal is generated by means of mechanic excitation in the body of the pipeline powerful law frequency acoustic vibrations. If there is no damaged pipeline, on the surface of the soil over it nominal level of acoustic signal in the range of excitation frequencies is registrated.

This level on condition of excitation vibrations stability is determined by the coefficients of sound attenuation and environment boundaries passage: the surface of metal pipeline – insulation – soil – air. If over the pipeline there are additional layers of covering (concrete, asphalt, etc.) their acoustic characteristics should be taken into account. If there is a fault in the pipeline, acoustic permeability between layers and correspondingly attention degree of acoustic wave changes.

Application of microphone method of control on the example of pipeline section of L1 length, located between two compartments with stop valves, is shown in Fig. 2. Pipeline section 1 (length L1), located in the soil 2, by means of flanges 3 is connected to stop valves 4 in each of the compartments on both sides of the pipeline. The pipeline itself has the insulation 5, covering its metal surface 6. On one side of the pipeline, in the place, where insulation is removed, the device for excitation of acoustic signals (magnetostrictive drill) 7 is located. By means of signal cable 8 it is connected to low frequency generator 9. Low frequency generator produces frequencies for excitation of magnetostricitve drill in the range from 2 up to 10 kHz.

Acoustic waves, excited by magnetostricive drill 7, propagate along metal surface of the pipeline 1 as in long waveguide. Part of the energy of acoustic wave propagates from metal pipeline 1 along its length to the surface of the soil, changing its characteristics depending on the availability of the fault.

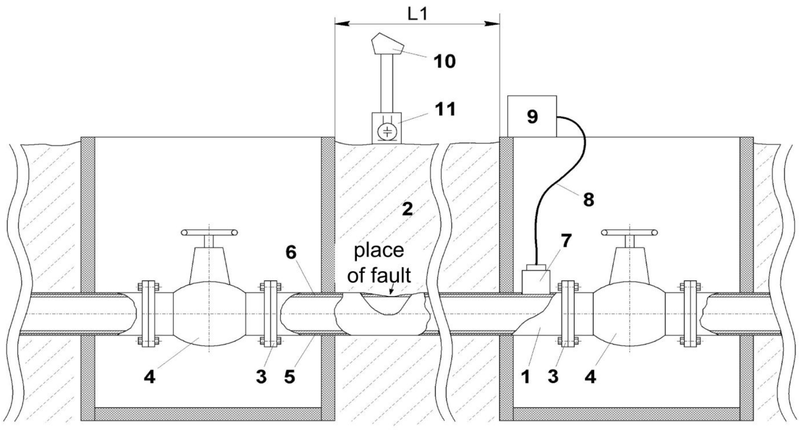

Fig. 2. Application of microphone method for the control of underground pipe line section, L1 of the length
1 – controlled section of underground pipeline, 2 – soil covering, 3 –flanges, 4 – stop-valves, 5 – external insulation of the pipeline, 6 – metal surface of the pipeline, 7 – device for excitation of acoustic signals , 8 – signal cable, 9 – low frequency generator, 10 – recording device, 11 –resonance chamber with measuring microphone

On soil surface acoustic response from the pipeline (sound pressure) is registered by measuring microphone of recording device 10. To increase the sensitivity and decrease signal-noise ratio measuring microphone of recording device 10 is located in resonance chamber 11.

Low frequency generator 9 has 10 operation modes.

Eight of them are responsible for frequency change in narrow range (2 – 3 kHz, 3 – 4 kHz, 4 – 5 kHz, 5 – 6 kHz, 6 – 7 kHz, 7 – 8 kHz, 8 – 9 kHz, 9 – 10 kHz), and two modes are responsible for amplitude change. Control of generator operation modes can be performed manually or from recording device 10 by means of radio channel.

As the research showed, frequency range from 4 to 5 kHz is the optimal range to perform the control. In this range acoustic signals from the pipeline are registered on the surface of the soil from the depth of more than 2.5 m.

Performing the control, using microphone method, the operator with recording device 10 moves along the section of the pipeline by maximum value of sound pressure at the frequency of magnetostricitive drill excitation, registrating its values with certain step. Depending of acoustic pressure change along the section of the pipeline and fixed frequency of excitation is shown in Fig. 3. In the place of fault, where, as a rule, insulation is damaged and the soil is wet, attention coefficients of sound wave change, that is manifested by the growth of sound pressure amplitude on the surface of the soil (Fig. 3).

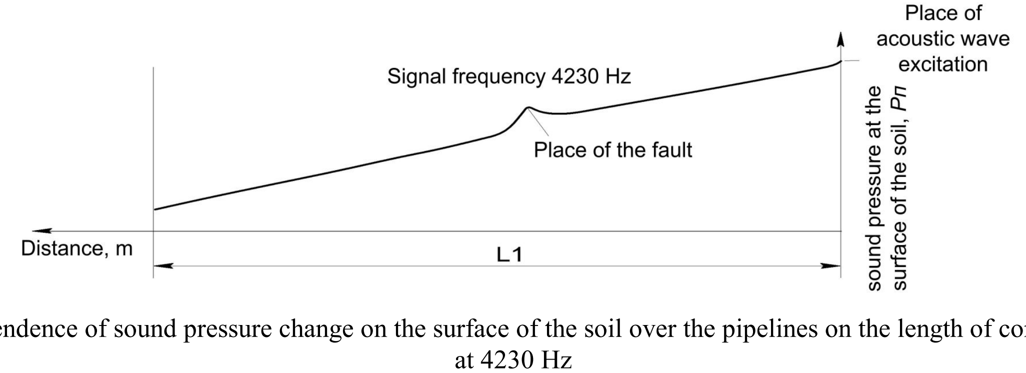

Fig. 3. Dependence of sound pressure change on the surface of the soil over the pipelines on the length of control section at 4230 Hz

Knowing the characteristics of the media, acoustic wave passes through, sound pressure P_A at any point over the pipeline can be calculated by the expression:

$$P_A = \sqrt{\frac{J \cdot c_T}{2 \cdot \pi^2 \cdot \rho_T^{\;2} \cdot r_T^{\;2} \cdot f^2}} \cdot \rho_T \cdot c_T \cdot T_{T/I} \cdot T_{I/Г3} \cdot T_{Г3/П} \cdot e^{(\alpha_T \cdot r_T + \alpha_I \cdot r_I + \alpha_{Г3} \cdot h_{Г3} + \alpha_П \cdot h_П)}, \tag{1}$$

where J –intensity of excited acoustic wave on the surface of the pipeline, V/m; c_p – sound velocity in the material of the pipeline, m/s; ρ_p – density of the pipeline material, kg/m^3; r_p – external radius of the metal pipeline, m; r_I – external radius of pipeline insulation, m; f – signal frequency of the excited acoustic wave in the pipeline, c^{-1}; $T_{P/I}$, $T_{I/SC}$, $T_{SC/air}$ – coefficients of acoustic wave passage on the boundaries of media (pipeline – insulation – insulation – soil covering – air); α_P, α_I, α_{SC}, α_{air} – attenuation coefficients of acoustic wave in various media (pipeline, insulation, soil covering, air); h_{SC}, h_P – length of acoustic wave route in soil covering and air, m.

Comparing real obtained value of sound pressure in certain points with calculated value, we can detect the fault of the pipeline.

If the characteristics of the media, where acoustic wave passes from the pipeline, are not known or above the pipeline there are several layers of various covering or communications, then by means of microphone method maximum value of sound pressure on the surface of the soil is registered. The axis of the pipeline can be determined, but it is impossible to reveal the faults in the pipeline.

To increase the probability of faults detection on short sections of pipelines it is suggested to use electromagnetic method with electric limitation of control section and increased control frequencies – application of electromagnetic method of control on the example of pipeline section of L1 length, located between two compartments with stop valves is shown in Fig. 4.

Metal clamps 7 are installed on the parts of the pipeline 1, liberated from the insulation, at the beginning and at the end of control section. Signal cables 9 from signals generator 10 and loading element 11 pass to these clamps across connecting terminals 8. Signals generators 10 and loading element 11 are grounded across ground electrodes 12, that electrically limit the area of control. Registration of the signal from the pipeline on the surface of the soil is realized by means of the device 13, using search coil 14.

Simplified equivalent circuit of electrically area of control is given in Fig. 5. At this area generator current I_1 acts, that is divided into the current, that passes across the loading element I_3 and the current across the fault of the pipeline I_2.The greater the area of the fault, the greater the value of I_2 will be. At short control sections in order to increase the information content and as a result of minor attenuation it is expedient to use high frequencies in the range of 20-30 kHz.

Specific linear resistances of equivalent circuit sections are calculated, taking into account diagnostic features according to known techniques [3, 4].

Values of currents and voltages, acting in equivalent circuit of pipeline section, are calculated according to the method of equivalent generator by the following:

$$I_1 = \frac{E_{XX}}{\left(Z_{\tilde{A}} + Z_T + Z_{\tilde{A}\hat{A}\acute{I}}\right) + \dfrac{\left(Z_{^{2}Ç} + Z_Ç\right) \cdot Z_{\tilde{A}\hat{A}\acute{I}}}{Z_{^{2}Ç} + Z_Ç + Z_{\tilde{A}\hat{A}\acute{I}}}}, \tag{2}$$

where E_{XX} – no-load voltage of signals generator, V; Z_S – specific linear resistance of the soil on control section, Ohm/m; Z_P – specific linear resistance of pipeline section, Ohm/m; Z_{GEN} – internal resistance of signals generator, Ohm; Z_{INS} – specific linear resistance of the insulation on pipeline section, Ohm/m; Z_S – specific resistance of the soil to drain currents on control section, Ohm/m.

$$I_2 = \frac{E}{Z_{INS} + Z_S}, \tag{3}$$

where E – e.m.f. of signals generator, V.

$$I_S = \frac{E}{Z_L}, \tag{4}$$

where Z_L – resistance of load element, Ohm.

$$E = I_1 \cdot \left[\frac{(Z_{INS} + Z_S) \cdot Z_{GEN}}{Z_{INS} + Z_S + Z_{GEN}} \right]. \tag{5}$$

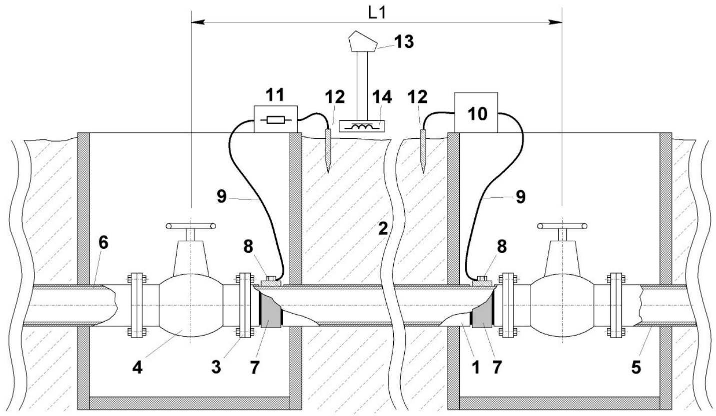

Fig. 4. Application of electromagnetic method for the control of underground pipeline section, L1 of length: 1 – controlled section of underground pipeline, 2 – soil covering, 3 – flanges, 4 – stop valves, 5 – external insulation of the pipeline, 6 – metal surface of the pipeline, 7 – metal clamps, 8 – connecting terminals, 9 – signals cables, 10 – signals generator, 11 – resistive element of loading, 12 – ground electrodes, 13 – registration device, 14 – search coil

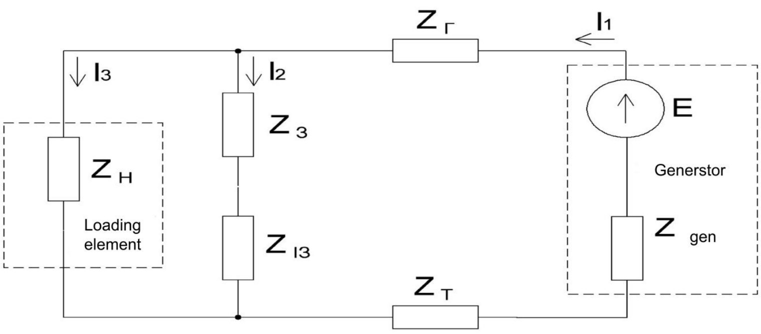

Fig. 5. Simplified electric equivalent circuit of underground pipeline section

When the control is performed, using electromagnetic method with electric limitations of controlled section, the operator with registration device 13 (Fig. 4) moves along the section to be inspected by maximal value of electromagnetic signal from the pipeline, registration its values with certain step.

Another important task of underground oil- gas-pipelines inspection is the possibility of distinct detection and identification of available faults of insulation covering. Among insulation faults we should distinguish continuous damages and ply separation.

Special attention should be paid to the inspection of minor length sections located in conditions of complex technological installations.

In order to identify the type of the fault of insulation coating we suggest to apply the combination of two electromagnetic methods of control: amplitude and phase. Electromagnetic amplitude method of control is based on the measurement of current value in the walls of the controlled underground oil- gas pipeline and the change of this value (attenuation) when it moves away from connected generator of input signal. Measurements are performed in points with prior selected stable step between them.

Electromagnetic phase method of control is base on the fact that the pipeline is presented by long line, characterized by distributive capacitance stipulates by the insulation and distributed inductance, that does not greatly depend on the parameters of the pipeline. The delay of signal propagation and phase shift change increases when the distance from AC generator, connected to the pipe- line increases.

Rate of phase change depends on the thinkness and state of insulation coating, that allows to make conclusions regarding its state. For determination of phases difference, reference signal, obtained from the generator should be used or operate at several frequencies simultaneously, using one of them as the reference one [5, 6].

Technique of inspections of insulation coating state of underground oil- gas pipelines on the territory of complex technological installations aimed at revealing and identification of available insulation faults comprises the following steps:

- carrying out measurements, using electromagnetic phase method of control (determination of specific phase shift between the control points);
- measurements of current values by means of electromagnetic amplitude method of control, using stable step between measurement points;
- reduction of the step between the points of measurements in the places of considerable specific change of current signal values in the walls of the studied oil, gas- pipelines (if necessary);
- comparison of the obtained results of control for analysis of the change of basic information parameters in order to obtain identification signs of this or that fault of insulation coating;
- analysis of the obtained results of control and formation of conclusions regarding the state insulation.

The suggested scheme of insulation state control of underground oil- gas pipelines, located on the territory of complex technological installations, is given in Fig. 6.

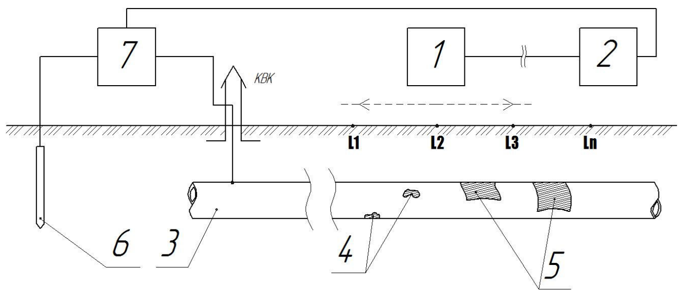

Fig. 6. Scheme of insulation coating state control of underground oil- gas pipelines
1 – portable measuring device, 2 – two-channel oscillograph ; 3 – investigated pipeline; 4 – continuous faults of the insulation ; 5 – scaling of insulation coating; 6 – grounding electrode; 7 – multifrequncy generator; CMC – control measuring calumn; L1, L2, L3,…, Ln – points of measurement

The essence of such control is the following. Multifrequency generator 7 via control-measuring column (CMC) is connected to the investigated pipeline 3 and to ground electrode 6. AC generator 7 creates the control signal that changes during its passage along the pipeline. Such changes are manifested in the form of signal propagation delay, that depends on electric parameters of underground oil, gas-pipeline, located in the soil. Signal measuring takes place in points L1, L2, L3,…, Ln with stable step by means of portable measuring device 1, when the operator moves long the axis of the investigated communication. When passing the places of continuous faults of insulation coating 4 or places of insulation ply separation 5 sharp jump of phase shift occurs. Registration of the signal, obtained by means of portable measuring device 1, takes place visually using two-channel digital oscillograph 2, at one of its inputs the processed signal from the investigated underground oil, gas-pipeline is sent. At the other input of the oscillograph 2 the reference signal from generator 7 is sent in order to evaluate the phase shift of the obtained signal relatively reference signal. In places of considerable specific phase shift the detection of insulation coating faults is most probable. Thus, usage of the single phase method of control enables to reveal both insulation scaling any continuous faults but it is impossible to perform exact identification of such faults. For this purpose we use amplitude electromagnetic of control, by means of which the continuous damages of insulation coating can be determined. Attenuation of current signal in case of usage of electromagnetic amplitude method of control may be registered if current leakage in the ground occurs, that is observed in places of the control of metal of the pipe with the ground in continuous damages of insulation coating. In case of scaling of insulation coating holes in the insulation, across which electrolyte filters in the body of the pipe are often small, that does not allow to register considerable changes of current values if such faults are available [7]. It should be noted, that considerable attenuation of the signal is possible even if tee of pipelines, T-joints, great changes in the depth of investigated pipeline bedding are available, whereas phase shift in such situations remains practically unchangeable [7].

Optimal frequency for realization of inspections of underground oil-gas pipelines sections of small length 33 kHz frequency has been selected, at this frequency changes of information parameters (values of current, phase shift) are readily recorded, also at this frequency the impact of strange hindrances in less sensitive. The selection of the frequency is carried out on the base of experimental results, obtained at special scientific practical testing ground and at operational installation of oil-gas complex [7, 8].

Hence, on the base of comparison of the results of two methods of control the conclusion can be drawn, regarding the form of available faults in insulation coating: in case of available simultaneous considerable changes of signal amplitude and phase shift at the same section we will speak about the presence of continuous damages of insulation, in case of the presence of only phase shift changes, the connection can be drawn regarding the ply separation of insulation coating (Fig. 7).

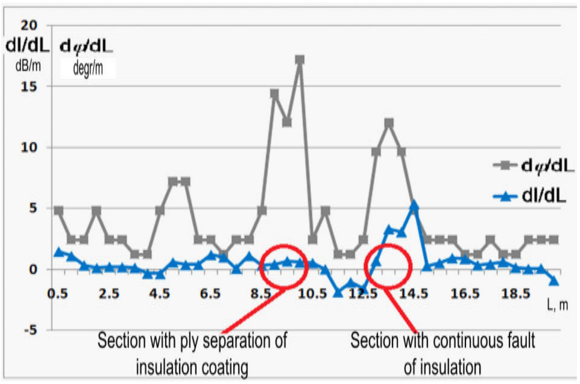

Fig. 7. Comparison of measurements results of two information parameters on the section of underground oil- gas pipeline (signal attenuation and phase shift change)

In case of necessity the section of control must be electrically limited, using additional ground electrode and loading element.

Conclusions, made from the given research and prospects of further studies in the given direction

Application of complex inspection of underground oil- gas pipeline will provide the possibility to increase the probability of the control of short non-direct sections of pipelines in places with high concentration of underground communications.

For further studies it is necessary to develop regulatory document, regarding the execution of such control. The document must contain types of faults of underground oil- gas pipelines, the technique of their detection and identification, as well as it should contain defective criteria, that will enable to regulate strictly the process of inspections and formulate correctly conclusions regarding the suitability for further operation or necessity to carry out the repair on the sections of underground oil- gas pipelines.

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