Evaluation of the Key Physical Factors Effect on the Corrosion Monitoring Device Performance

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Abstract. Municipal systems that provide optimal living conditions for the population are designed for decades of trouble-free operation. The majority of accidents on pipelines of municipal networks appear as a result of corrosion and mechanical damages of the pipeline material, determination of the place, time and nature of which is difficult to predict and is associated with significant material costs. The basis of measures to prevent and eliminate emergencies caused by accidents at public utilities, as well as to reduce possible losses and damage from them put preventive measures of scientific, engineering and technological nature. These measures include improving the operational reliability of systems, the creation and use of effective control systems, technical diagnostics, forecasting, localization and emergency response. Using the device monitor internal corrosion of pipelines changes in operating conditions allows to estimate the depth of corrosion changes in the thickness of the tubing, to predict the time of achievement of corrosive changes in marginal values pre-crash and thus preventing the occurrence of an emergency situation. The article is devoted to evaluating the accuracy of measuring the corrosion depth of pipeline systems for gas supply, water supply and sewerage of municipal utilities under the influence of external factors.

1. Introduction

At present, a rather difficult problem for the public utilities providers is to maintain the operational capabilities of pipeline systems for gas supply, water supply, and sewerage at the proper level [1]. The pipes corrosive wear is influenced by the environment, aging of the pipeline material, including corrosive deterioration. Regardless of the nature of the causes of operational wear, it is necessary to establish continuous monitoring of the public utilities condition.

The main problem of monitoring corrosion changes in urban utilities supply pipelines is the difficulty of measuring the thickness of ferromagnetic conductive pipes during their operation. The primary information collection devices should provide continuous (periodic) monitoring of the pipe wall thickness in automatic mode without using the in-line flaw detectors or digging test holes. The main pipelines corrosion monitoring device developed by the authors can be used as such an intelligent sensor [2]. The essence of the engineering solution in terms of the measurement method is that on the main pipeline, at the site of the most severe corrosive changes, the exciting and measuring inductance coils are located, covering the pipeline. Thus, the pipe acts as a magnetic conductor of a transformer eddy-current transducer (eddy-current probe), and EMF induced in the measuring coil will depend on the pipe parameters and its thickness in particular [3].

The technical implementation of the device involves using two drive inductance coils (exciting coils) connected in series in Helmholtz arrangement and measuring coil placed between them, a
frequency-tunable test-signal generator, a pipe temperature sensor, and a digital computer. The EMF induced in a measuring coil is pre-amplified by a broadband amplifier and is filtered by a tunable bandpass filter to increase noise immunity and protect from random interference [2,3].

The EMF induced in the measuring coil is highly temperature-dependent as the magnetic permeability of ferromagnetic materials increases nonlinearly when they are heated. In addition, the measurement results are influenced by currents induced by the electromagnetic field in the pipeline material [4].

Thus, the purpose of the given research is to evaluate the accuracy of the corrosion depth measurement results under the influence of the factors listed above.

2. Method and structural scheme

The following experiments were carried out to test the performance of the monitoring device:

• studying the influence of currents arising from extraneous sources on the monitoring device performance [5,6,7];
• studying the influence of the object temperature on the corrosion indicators [8].

The influence of the thick-walled pipe temperature on the amplitude and phase parameters of corrosion wear was evaluated in the heat-cold chamber (TT-60/135-250 KTH model) (Figure 1). For the studies, a section of a thick-walled pipe with a diameter of 76 mm, wall thickness of 15 mm and a length of 300 mm was used (Figure 2).
The measuring and exciting coils were wound with a PLC-0.2 wire in four sections of 50 turns each. Two sections of the exciting coil were located on the outer sides of the two sections of the measuring coil. To measure the temperature, a standard temperature sensor of the heat chamber (measurement accuracy 1° C) and a digital sensor Dallas Semiconductor DS1820 (measurement accuracy 0.5° C) were used. The Dallas Semiconductor DS1820 digital sensor was placed directly on the pipe in the coil area.

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3. Numerical modeling

Figure 3 presents graphs reflecting the dependence of the amplitude of the signal induced in the measuring coil, on the temperature at frequencies of 100, 200, 300 and 400 Hz. As appears from the graphs, for the most part of the operating frequency range, the dependencies are linear with a constant coefficient of proportionality.

The amplitude of the induced voltage in the measuring coil decreases with increasing temperature. A decrease in the amplitude of the signal with increasing temperature can cause false decision about the presence of corrosive changes. This fact confirms once again the correctness of the decision to control the temperature of the object during the monitoring [4].

Figure 4 shows graphs of corrosion indicators depending on the temperature of the object. As follows from the graph of the temperature dependence of the amplitude index, the temperature increment by 5 degrees is similar to the change in the depth of pitting corrosion by 0.5 mm.

Figure 3. Effect of the object temperature on the amplitude of the input signal

Figure 4. Dependence of the amplitude indicator of corrosion on the object temperature

According to the graph demonstrating the change of the input signal’s amplitude from the temperature at a frequency of 200 Hz (see Figure 5), a linear approximation can be obtained:

\[ u(T) = kT + b, \]

Where \( k = \Delta u/\Delta T = -0.0025 \) is a proportionality coefficient; \( b = 0.112 \) is the value of the input signal amplitude at a frequency of 200 Hz at zero temperature.
Thus, as a result of the research we can draw the following conclusions:

- the influence of the object temperature on the value of corrosion indicators is significant and must be taken into account when monitoring;
- when processing the results of corrosion indicators measurements and obtaining a forecast of corrosion changes, it is necessary to carry out the normalization of the corrosion indicators and take into account the multidirectional change in the phase index with an increase in the depth of pit corrosion and temperature.

Main steel pipelines are laid directly in the ground in the areas of stray currents; therefore various electrochemical methods are used to protect them [11].

To protect underground pipelines from corrosion caused by stray currents, drainage protection is used (polarized or enhanced drainage). In cases when the use of polarized and enhanced drainage is unreasonable due to technical and economic considerations, cathodic protection of underground structures against corrosion caused by stray currents is used [12].

Anodic protection is used to protect underground structures against corrosion caused by stray currents in the anodic and alternating zones, when the magnitude of stray currents can be compensated by the protector current and when the required value of the protective potential is provided [13].

Thus, the measuring coils of the corrosion monitoring device are influenced by currents originating from soil, or currents from DC transmission lines operating through the wire-to-ground system, if any in the area, as well as currents caused by the operation of the electrochemical protection equipment.

To evaluate the influence of stray currents on the corrosion monitoring device performance, a number of experimental studies have been carried out.

The influence of the electric current extraneous sources was evaluated using two types of interference sources: a direct current source and an alternating voltage source with a frequency of 50 Hz.

To conduct research on the pipe section opposite sides, contacts were welded in to fasten the wire with a cross-section that provides current flow up to 100 A. In series with the pipe section, a high-power current limiting resistor was connected, and an ECP current source was connected.

A series of experiments were carried out with an increase in the current flowing through the pipe across the direction of the winding of the exciting and measuring coils [5,8].

Figure 5 shows the dependency graphs of the amplitude of the voltage signal induced in the measuring winding as a function of the external source current at frequencies of 100, 200, 300 and 400 Hz. As follows from the graphs, the absolute value of the amplitude increment is small and does not exceed 0.005 V.

Figure 6 presents a graph showing the dependence of the amplitude indicator of corrosion on the strength of the external source current.

![Figure 5. Influence of the ECP current strength on the amplitude of the input signal](image1)

![Figure 6. Dependence of the amplitude indicator of corrosion on the strength of the external source current](image2)
The analysis of the graph shown in Figure 6 allows drawing the following conclusions:

- The amplitude indicator increment value is about 0.001 V per electric current increment of one ampere;
- The electric current of 40 A is comparable in terms of the corrosion index value with pitting corrosion with a depth of less than 1 mm.

The influence of an alternating current source with a frequency of 50 Hz was modeled by means of a series connection of the transformer output windings, an active resistance of 200 Ohms, a capacitor with a capacitance of 15 uF and a segment of the pipe under study. Voltage reduction in the primary winding was achieved using a laboratory autotransformer (LATR).

Figure 7 shows the graphs for the amplitude of the signal induced in the measuring winding when measuring at frequencies of 100, 200, 300 and 400 Hz under the action of an alternating current interference with a frequency of 50 Hz of various amplitudes.

As follows from the graphs, the influence on the input signal amplitude has been observed, but the absolute value of the amplitude increment is small. The conclusions have been confirmed by the graph for the corrosion indicators presented in Figure 8.

Analysis of graphs allows us to draw the following conclusions:

- Interference in the form of an alternating voltage with a frequency of 50 Hz has a greater impact on the amplitude indicator of corrosion than interference from a constant electrical current source;
- The absolute increment of the alternating voltage amplitude by 10 V provides a change in the amplitude indicator of corrosion by an amount, equivalent to an increase in the depth of pitting corrosion by 3 mm, but when exposed to an external source of interference, the amplitude indicator increases but not decreases its zero value and is practically not subject to interference.

4. Conclusions

The approximation of the amplitude indicator temperature dependence by a linear function allows the normalization of the obtained values to any temperature. The measurements temperature conditions were monitored with an accuracy of 0.5° C and recorded in an external storage device. Extraneous voltage interference with constant and alternating current directions has a slight impact on the amplitude indicator of corrosion.

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