Inspection of corrosion defects of steel pipes by eddy current method

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Abstract. The article describes the results of testing a known non-destructive eddy current inspection method intended for non-destructive testing of steel pipelines. The analysis of the operational capabilities and features of this type of test objects showed the need for the development of new approaches in the field of creation of measuring sensors and software-hardware systems for pipelines' technical inspection. The feasibility of creation of a measuring system capable of searching for defects with the diameters from 0.2 mm located at a depth of 2 mm is demonstrated. In the proposed method and its schematic design, the impact of a defect on the magnitude of the transformer EMF induced in the measuring winding of the eddy-current sensor is used. The article investigates the influence of the size and depth of the defect on the eddy-current sensor EMF and analyzes the influence of these parameters on the obtained signal dependences in order to determine the defect parameters.

1. Introduction

In the current manufacturing practice, there are a number of ferromagnetic products and structures with a large test surface attributable to their length. In particular, such products include pipelines. One of the major problems of the present-day pipeline systems operation is the necessity of their total replacement after expiration of the standard service life. As an alternative to complete replacement, the replacement of only the defective sections of the pipeline might be necessary for ensuring their safe operation, which requires a non-destructive testing through the full length of the pipeline with high effectiveness and speed, capable to recognize various types of defects that can occur in these systems [1].

If it is necessary to ensure high-quality non-destructive testing of the product, both the parameters of the product being inspected and the nature of the identified defects, as well as their relative position and influence upon the measurement results should be taken into account. The product material is also of no small importance.

The defects in a product under inspection can vary in size, shape and depth. Surface defects and those occurring at a depth of not more than 1 mm are relatively easily determinable by standard non-destructive testing methods (ultrasonic, eddy-current, magnetic particle tests), whereas solely the ultrasonic and sometimes X-ray methods are usually used for identification of deeply occurred defects.

The eddy current method is usually used to monitor surface defects in metal structures by taking advantage of the skin effect. However, defects often occur in the inner walls of oil or gas pipes as a result of corrosion or erosion.

One of the common defects in pipeline systems is cracking with different openings and depths.
Most of the defects begin on the exterior surface of pipe strings and grow as longitudinal cracks [2-3]. But in some key positions, such as girth weld, transverse cracks are the common defects on pipe strings [4-5]. As the crack grows up, it can lead to the failure of pipe string and bring about serious accidents and injuries [6-8].

For such defects, the effectiveness of eddy current inspection is determined by its automation and process mobility. Acceleration of the process makes it possible to reduce the cost significantly and increase informational value of non-destructive testing of pipeline systems. In this connection, a topical objective is the development of a hardware-software complex that would provide defect finding in ferromagnetic piping systems.

2. Materials and methods

For scanning the test pipelines with defects, a subminiature eddy-current transducer with a measuring winding diameter of 0.2 mm was used. The presence of a defect was determined by the eddy-current transducer signal amplitude decay due to the appearance of a local magnetic anomaly in the defect region.

Sensing signals contain the size and shape information of defects so that it is necessary to make a decomposing or estimating algorithm for the sizing and shaping of defects in the pipeline maintenance [9], [10]. In the conventional method, the depth size of defect could be estimated simultaneously with axial length and circumferential width, which makes it hard to estimate defect depth correctly because the depth signals are closely related to the length and width signals. The depth estimation is inevitably affected by the estimation errors of defect length and width together [11].

The degree of defectiveness was estimated by comparing the recorded ECT signal amplitude decaying as compared with the signal amplitude when scanning the defect-free part of the test object.

The main parameters of the developed eddy-current differential transducer [12-13]:

- Excitation frequencies: 500 Hz, 1500 Hz, 3000 Hz.
- Excitation winding internal diameter: 0.2 mm.
- Measuring winding internal diameter: 0.08 mm.
- Coil spacing: 0.2 mm.
- Number of excitation winding turns: 50.
- Number of measuring winding turns: 200.

The transducer also contained a compensating winding with an opposite connection to the measuring winding. Due to such connection circuit, the output signal of the transducer is equal to zero in the absence of a test object near the sensor.

The excitation frequencies were chosen so that the penetration depth of the electromagnetic field into the test object was greater than the measured pipe thickness for the low frequency, and for the medium and high frequencies, the penetration depth should be less than the pipe thickness, but sufficient for recording the signal EMF changes in the presence of defects in metal.

In general terms, the design of the developed hardware and software complex is as follows: the voltage source supplies direct current to the PC-controlled Arduino Uno digital microcontroller. The computer-controlled microcontroller generates a sinusoidal signal, which is then amplified by a programmable amplifier.

The characteristics of the amplifier are set so that the maximum signal amplitude would be at a given frequency. This signal is transmitted to the exciting winding of the ECT, following which a magnetic field is generated that excites eddy currents in the test object (TO). Eddy currents in the TO generate their own electromagnetic field, which generates a signal in the form of EMF in the measuring winding of the ECT. This signal passes through the compensation unit, necessary for zero signal generation in the absence of the test object, and then it is amplified by a special amplifier. For noise suppression, an active noise reduction channel was introduced into the circuit in the form of a two-stage Delyann filter. The signal purified by the filter is transmitted to an analog-to-digital converter and the PC computing unit.

The computing unit converts the output signals of the eddy-current transducer into a measurable
value of the inspected parameter using the conversion functions, determined experimentally on various types of pipes of different thicknesses and steel grades.

The PC computing unit performs analog-to-digital converter signal receipt and processing, data displaying and results storage.

3. Results and discussion

In order to illustrate the serviceability of the developed software and hardware complex, various sections of pipelines 3 mm thick, containing model defects, were used. The defects were modeled by drilling with a diameter of 0.2-1 mm. Drilling was performed from the inside of the pipeline to a depth of 1-2.6 mm, the eddy-current transducer was placed on the outside of the pipeline. Model defects on test items simulate real damages usually caused by corrosion. The main objective of the experiment was to determine the sensitivity of the developed flaw detector to subsurface defects and detect the dependence between the ECT signal and the defect depth. The experimental results are shown in Figures 1-3.

Figure 1. Dependence between the eddy-current transducer signal and defects of 0.2 mm in diameter drilled to various depths. 1 – 1 mm, 2 – 1.8 mm, 3 – 2.6 mm

Figure 1 illustrates the dependence between the eddy-current transducer signal and defects of 0.2 mm in diameter drilled to various depths. It is clearly seen that the transducer signal amplitude is being increased over the defect as approaching the surface, and this signal amplitude increase occurs exponentially. The change of the amplitude of a signal when it passing above the defect itself varies from 0.2 V to 0.7 V, depending on the defect depth. In the vicinity of the defect, the ECT signal remains almost unchanged as compared with the signal from the defect-free part of the test item.
Figure 2. Dependence between the eddy-current transducer signal and defects of 0.6 mm in diameter drilled to various depths. 1 – 1 mm, 2 – 1.8 mm, 3 – 2.6 mm

When scanning a defect with a diameter of 0.6 mm drilled to various depths, changes in the signal amplitude become noticeable even when approaching the defect (Figure 2). When scanning the defect-free part of the test item, the mean square deviation of the signal amplitude did not exceed 0.05 mV, and when approaching the defect, this value was 0.2 mm. At that, the change in the signal amplitude when passing above the defect itself was from 0.3 to 0.9 V, which slightly differs from the change in the signal amplitude when passing above the defect of a smaller diameter.

Figure 3. Dependence between the eddy-current transducer signal and defects of 1 mm in diameter drilled to various depths. 1 – 1 mm, 2 – 1.8 mm, 3 – 2.6 mm

When scanning a defect with a diameter of 1 mm drilled to various depths, changes in the signal amplitude are also clearly noticeable when approaching the defect. When approaching the defect, the mean square deviation of the signal amplitude significantly exceeds that for the defect-free part of the test item, however, a significantly greater change in the signal amplitude when passing above the defect itself is noteworthy. It varies from 0.6 to 1.5 V, which is far in excess of the changes occurring when the signal passes above a defect of a smaller diameter. At that, the change in amplitude itself develops more smoothly as compared with defects of smaller sizes.
When scanning pipelines, a situation is often observed when the surface of the scanned area is covered with a layer of non-conductive paint coating. Because the traditional eddy current testing (ET) is sensitive to lift-off, it needs a higher degree of surface clearness [14]. During the second experiment, a polyethylene layer 0.1-0.5 mm thick was placed over the sample in order to determine the effect of the nonconducting layer on the ECT signal amplitude. The measurement results for a defect with a diameter of 0.6 mm located at various depths are presented in figure 4.

![Figure 4. Dependence between the eddy-current transducer signal and defects of 0.6 mm in diameter drilled to various on the gap. 1 – 0.1 mm, 2 – 0.5 mm](image)

These figures demonstrate low dependence of the signal amplitude on the gap to a drilling depth of 2 mm, which is about 65 percent of the total pipe thickness. As compared with Figure 2, the changes of signal amplitude were about 7-15%. As the drilling depth increased and, as a consequence, the defect got closer to the test item surface, the influence of the nonconducting layer on the ECT signal also increased. At a drilling depth of 2.6 mm, the deviation of the maximum change in the signal amplitude was about 50% as compared with the results presented in Figure 2.

4. Conclusion

Thus, a conclusion may be drawn about the optimal scanning of various types of defects and a parameter carrying useful information about its depth and linear size. When searching for small defects, it is more convenient to use instantaneous changes in the signal amplitude, indicating the passage of the transducer signal over the defect. In case of increase in the mean square deviation of the ECT signal amplitude next to the change in amplitude that occurs when signal is passing above the defect, a conclusion may be made that there is a medium or large sized defect. However, a greater drop in the signal amplitude may indicate a defect with medium linear dimensions, and a smoother amplitude drop may be indicative of a defect with large linear dimensions that exerts influence on the ECT signal much earlier than smaller defects do.

At that, the presence of a layer of a nonconductive substance, for example, a lacquer coating has a slight impact on the ECT signal at small depths and a greater distance from the scanned surface. However, it starts to exert quite strong impact when the defect is located close to the transducer near the surface of the test substance.

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