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# Measuring Parameters of Defects using Alternate Metal Magnetization Method for In-line Inspection

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## Abstract

**Background/Objectives**: The purpose of this work is to develop a new method of non-destructive inspection for measuring defect parameters during the in-line inspection, without prior preparation of internal surface of the pipe. **Methods**: The basic principle behind this method is to form a magnetic field inside the pipe. In cases which show mechanical damage on the pipeline inner or outer surface, increased magnetic field amplitudes appear. Measurements of the value of the magnetic field amplitude along the pipeline inner surface enable to detect the defect occurrence and to evaluate the defect transverse dimensions and depth based on the magnetic peak height and width. **Findings:** The article provides a detailed description of the magnetic field changes in the defect localization area and presents an algorithm for determining the pipeline wall loss. A measuring sensor is selected; the choice of sinusoidal alternating current passing through the pipe body is justified and the principle of the developed method implementation is described. Also, an experiment has been conducted in which it was found that the magnetic field amplitude depends on the defect depth. The smaller pipeline wall loss in the defect zone, the higher the magnetic field variation is. Thus, the experiment confirms the validity of the non-contact magnetic method for pipeline NDT with alternating magnetization of metal. The novelty of the method lies in the possibility to conduct the non-destructive inspection of the pipeline without prior surface preparation, through a layer of corrosion and slime deposits, providing the clearance up to 20 mm between the pipe wall and the measuring sensor, with the probability of defect detection making 0.9. **Applications/Improvements:** This method provides solution for timely inspection of corrosion damage in subsurface pipelines of small-diameter heating networks (DN200, DN400) of housing and public utilities in places inaccessible for external inspection.

**Keywords:** Alternate Magnetization, Defect, In-Line Inspection, Magnetic Field, Non-destructive Testing, Pipeline, Slime Deposits, Thickness Measurement

## 1. Introduction

In-line Inspection (ILI) is an important process of pipeline maintenance, safe and reliable operation of pipeline systems depends on its quality and frequency.

The main problem with the ILI is the need for prior processing of pipe inner surfaces by removing corrosion by-products and sludge deposits, which can reach considerable thickness, since deposits overlap partially or completely the pipe body, preventing the delivery of diagnostic equipment.

To solve this problem, magnetic methods are optimal among the existing NDT methods,[1–7] since they are used without any direct contact of the system measuring sensor with the monitored item. The presence of salt deposits in the pipes hampers the movement of powerful magnetic systems over a rough surface, and the use of the usual magnetic method for pipeline testing in the energy and utilities sectors is difficult.

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Thus, there is a need to develop a new NDT method for ILI, enabling to measure the pipe wall thickness without prior surface preparation – through a layer of corrosion and sludge deposits while maintaining high performance.

The purpose of this article is a detailed description of the developed NDT method for ILI.

## 2. Magnetic Fields in the Defect Localization Area

The basic idea behind the developed method is to form a magnetic field inside the pipe as such, since the magnetic field inside a uniform undamaged pipeline is homogeneous. However, in cases of potential mechanical damage on the pipeline outer or inner surface, increased amplitude of the magnetic field occurs. By measuring the value of the magnetic field amplitude along the pipeline inner surface, it is possible to detect a defect available, and to evaluate the defect transverse dimensions and depth based on the height and width of the magnetic peak.

Figure 1 shows a section of the pipeline, through which alternating current flows. The figure corresponds to a certain point in time when the current amplitude is at its maximum value. Alternating current generates an alternating magnetic field around the pipe, the magnetic flux lines of which are closed around the pipe. The magnetic field penetrates into the pipe body to a depth equal to the skin layer, i.e. alternating current is distributed non-uniformly over the pipe cross section, but preferably in the surface layer. If there is a defect on the pipe surface, the magnetic field existing inside the monitored item bends accordingly around the defect.

The presence of sludge deposits on the inner surface of the pipeline results in the formation of a large gap between the pipe wall and the measuring sensor of the system (up to 20mm), which in turn imposes high sensitivity requirements for the measuring sensor.

The main types of magnetic field sensors are Hall effect-based sensing devices, inductance coils, and magnetoresistive sensors.

Magneto-resistive and Hall effect-based sensors have similar operating principles and sensitivity: from 5 to 50 V/T (from 0.5 to 5 mV/Gs). The inductance coil sensitivity to the magnetic field depends on the coil dimensions, the core parameters and the magnetic field frequency. By increasing the number of coil turns (over 1,000), the sensitivity will be significantly higher than the typical values shown by magneto-resistive sensors and Hall sensors. Therefore, it is expedient to use the inductance coil as a measuring sensor for the method implementation.[8–11]

Because of the noise interference when receiving an output signal from the measuring sensor there is a difficulty in recognizing minor defects (minimal variations in the magnetic field). Harmonic (sine-wave) signals have a narrow spectrum, making them easier to detect in the presence of a large amount of noise.

Therefore, for calculation simplicity and convenience of information processing sinusoidal alternating current is used as an electrical signal.

The magnetic field inside the pipe caused by a defect will be approximately by two orders of magnitude less

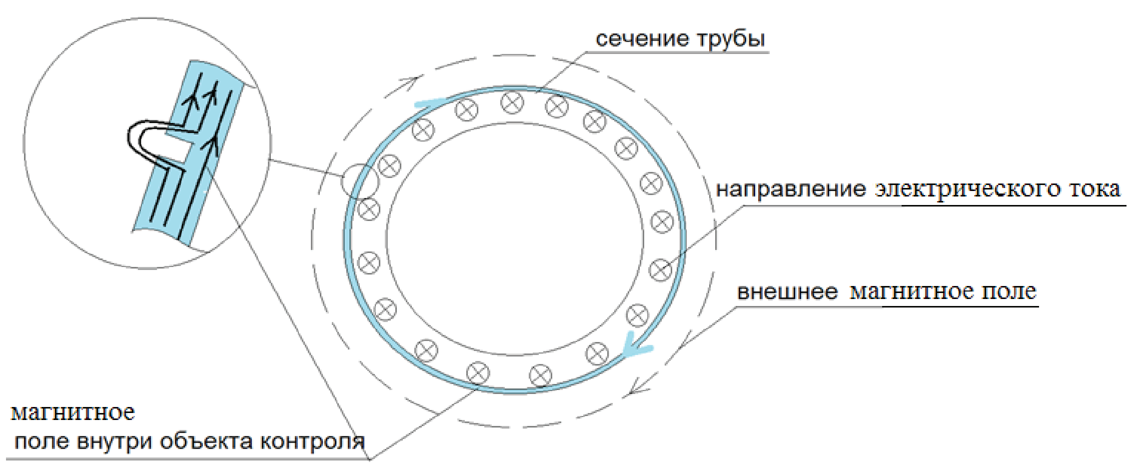


**Figure 1.** Distribution of magnetic field in the pipeline with surface defect.

than the external magnetic field and the field in the vicinity of the pipe section. Therefore, it will be impossible to identify a defect located close to the pipe end due to the overlapping of one stronger field on the pipe edge over the weak field of the defect. Range is a key factor that will enable the magnetic field inside the pipe to decrease to the acceptable level; that is why it is strongly required to start measurements some distance away from the pipe section.

To validate the non-contact magnetic method for pipeline NDT with alternating magnetization an experiment was carried out.

The generator forms a sine-wave signal with a frequency of 300 Hz.

The signal is then supplied to the audio power amplifier (hereinafter APA) to be used as a current source. Current amplitude is monitored using the current shunt and a voltmeter (see Figure 2).

Current flowing through the pipe generates an alternating magnetic field. The signal from the sensor is fed to the amplifier and measured using an oscillograph.

The ferrite core coil was selected as a measuring probe; the coil is wound on a plastic frame containing 1,500 turns. The physical configuration of the sensor is shown in Figure 3.

Low-alloy steel pipe 400 mm in diameter, 10 m long, having wall thickness 12 mm, is used as a monitored item, the pipe was made of 09G2S steel grade.

To obtain statistical data external and internal defects were applied on the pipe by flat bottom drilling, defect depths being 10 mm, 8 mm, 6 mm, 2 mm; defect diameter being 35mm. To eliminate the impact of some defects on the other ones, defects were spaced from each other at a distance of not less than 300 mm (along the pipe axis) and not less than 3,000 mm away from the pipe ends (see Figure 4).

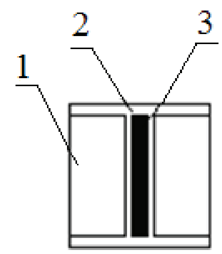


**Figure 3.** Measuring sensor design
1 – winding 2 – plastic body 3 - ferrite core.

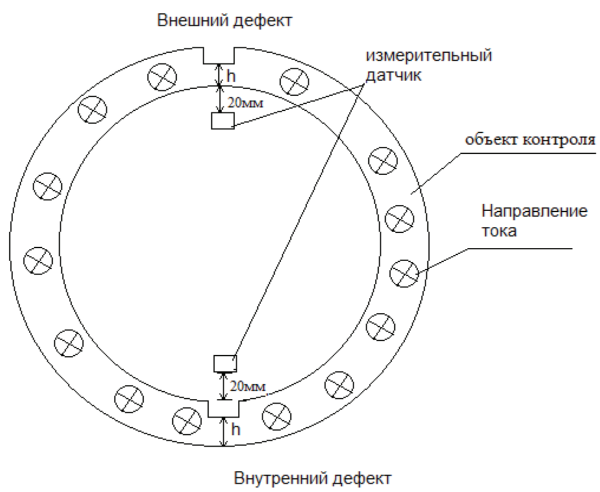


**Figure 4.** Location of defects in the pipe (h – pipe wall loss).

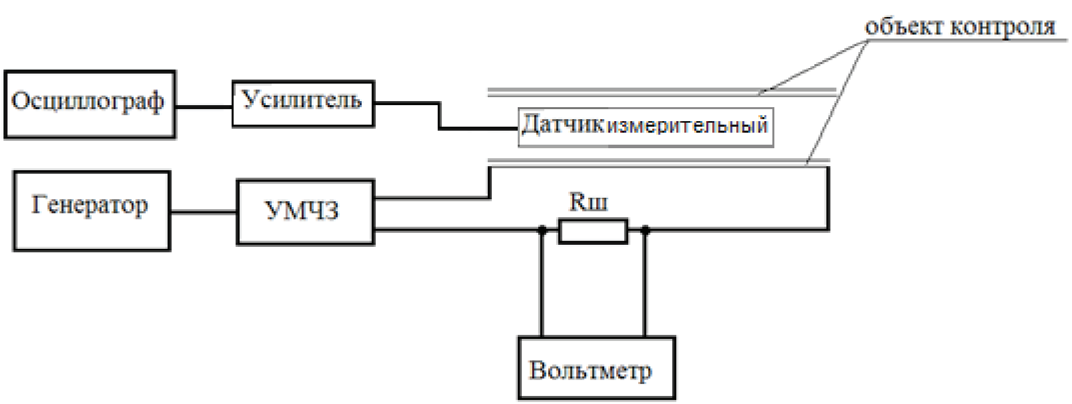


**Figure 2.** Plant schematic structure.

Defect tolerances made ±0.1mm. Detection probability was set out by the researcher as 0.9 for all types of the applied defects.

## 3. Results and Discussion

The experiment was carried out in the following sequence:

In accordance with the scheme shown in Figure 2 the equipment was connected. A scale grid with spacing of 12 mm was applied on the pipe inner surface. The alternating signal frequency and current amplitude were set out by means of the generator and APA. Current was passed through the pipe to generate the magnetic field, at the same time the amplitude of the signal displayed on the oscillograph was controlled. In each node of the grid scale 50 measurements of the magnetic field amplitude were made with the help of a measuring sensor mounted at a distance of 20mm from the pipe inner surface. The values of the signal amplitude were recorded with the oscillograph. The probability of detecting defects 10mm, 8mm and 6mm deep was 0.95 and 0.9 for the defects 2mm deep. The experiment yielded an array of data representing a magnetogram (Figure 5). The magnetogram shows the results for the defect sized 6x35 mm (metal wall loss amounts to 50%) as the most clearly demonstrating the identification of defects.

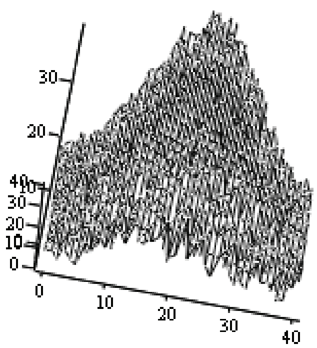


**Figure 5.** Experimentally obtained distribution of magnetic field amplitude nearby flat-bottomed drilling sized 6 × 35 mm.

Initial magnetogram, used for thickness calculation, is processed with the matched filter made as a matrix.

The filtered, smoothed signal is passed through the next filter:

$$yp_1 := |\, y_{i+1} - y_i \,|$$

As a result of filtration, spurious signals that typically vary slower than the useful signal from the defects become much smaller. Physical configuration of *yp* function versus the angular coordinate, in case of defects, is shown in Figure 6.

The figure demonstrates peak bifurcation; calculation of thickness requires smoothing the split peaks.

A differentiated signal is passed through the filter:

$$vy_i^{'} \frac{\sum_{j=1} K\left(\frac{vx_i - vx_j}{b}\right) vy_j}{\sum_{j=1}^{n} K\left(\frac{vx_i - vx_j}{b}\right)}$$

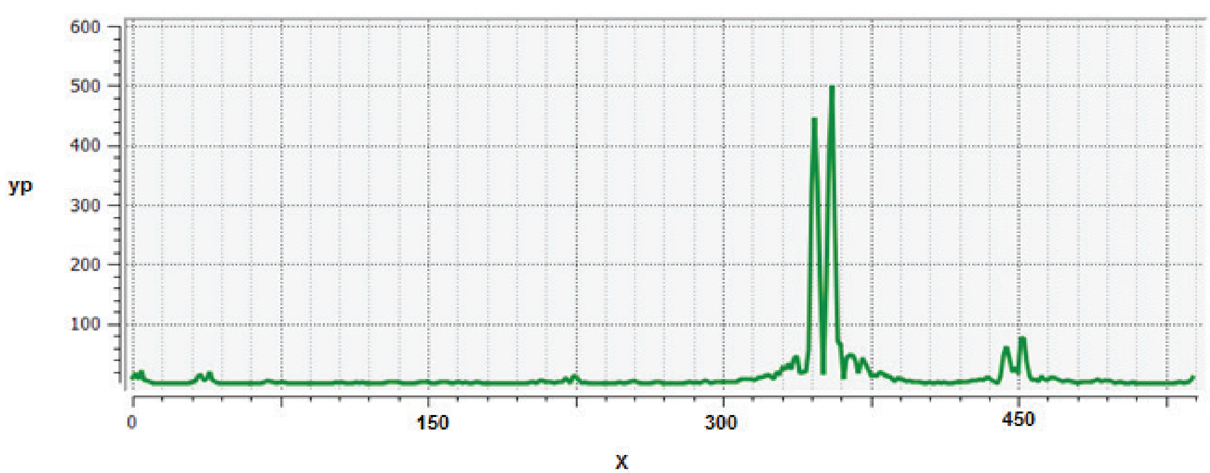


**Figure 6.** Physical configuration of data sampling after differentiation for the defect flat-bottomed drilling sized 6 × 35 mm.

where

$$K(t) = \frac{1}{\sqrt{2\pi}(0.37)} \cdot \exp\left(-\frac{t^2}{2.037^2}\right)$$

Filtration results in obtaining samplings close to the smooth functions, where each defect is determined by one peak. An example of the filtered sampling is shown in Figure 7 in comparison with the data without filtering.

Further, in order to find the thickness, the maximum search algorithm is used above the threshold by determining the peak "width".

According to measurement data the relationships between according to the maximum amplitudes of voltage U (mV) on the sensor over the defect and the wall loss h (mm) were constructed (see Figure 8).

The curves show that the amplitude of magnetic field strength depends on the defect depth. The smaller pipeline wall loss in the defect zone, the higher the magnetic field variation is.

Thus, the experiment conducted confirms the validity of the non-contact magnetic method for pipeline NDT with alternating magnetization of metal.

## 4. Conclusion

This article describes a new NDT method with alternating magnetization of metal.

The novelty of the developed method lies in the possibility to carry out nondestructive testing of the pipeline state without prior surface preparation with probability of defect detection making 0.9, through the layer of corrosion and sludge deposits, providing a gap up to 20mm between the pipe wall and the measuring sensor of the system. A high-sensitive inductive probe is used as a measuring sensor.

The article presents the algorithm for pipeline wall loss determination and gives the description of the conducted experiment confirming the method validity.

## 5. Acknowledgement

The research is carried out in compliance with ARAD "Applied research on creation of a new non-contact magnetic method for nondestructive testing of pipelines with alternating magnetization of metal and advanced development of an experimental prototype of an in-line robotic system based on this method providing solution to the timely inspection of corrosion damage in

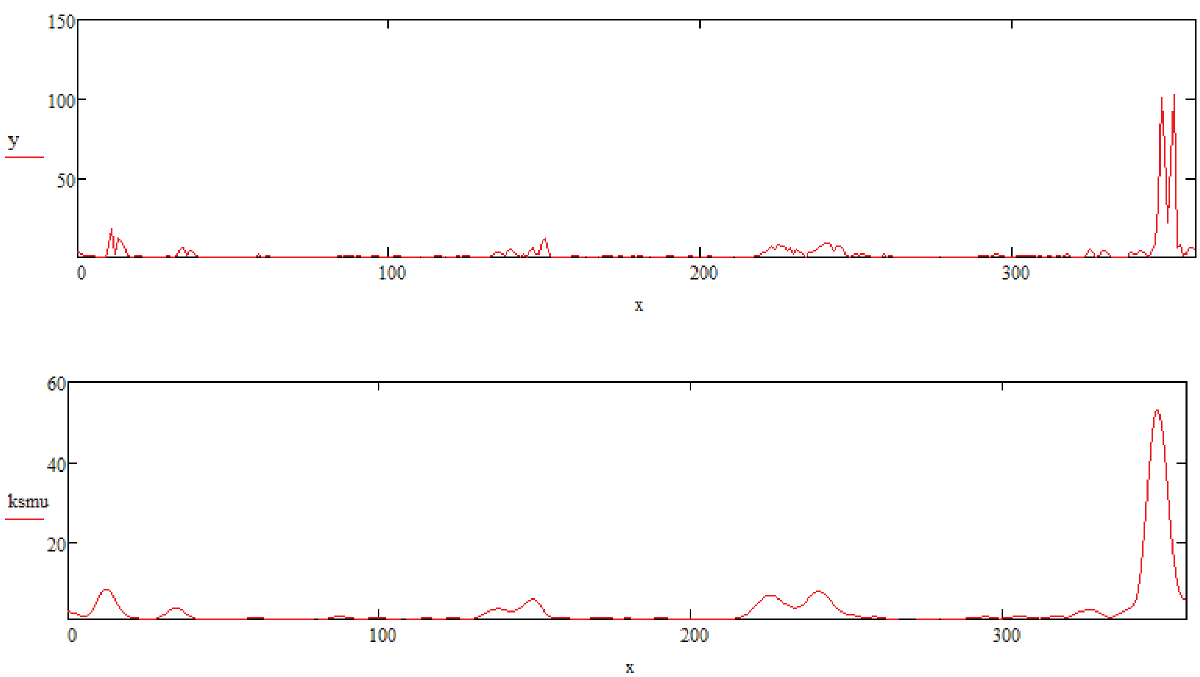


**Figure 7.** Comparison of the initial data – y and filtered ksmu for the defect flat-bottomed drilling sized 6 × 35 mm.

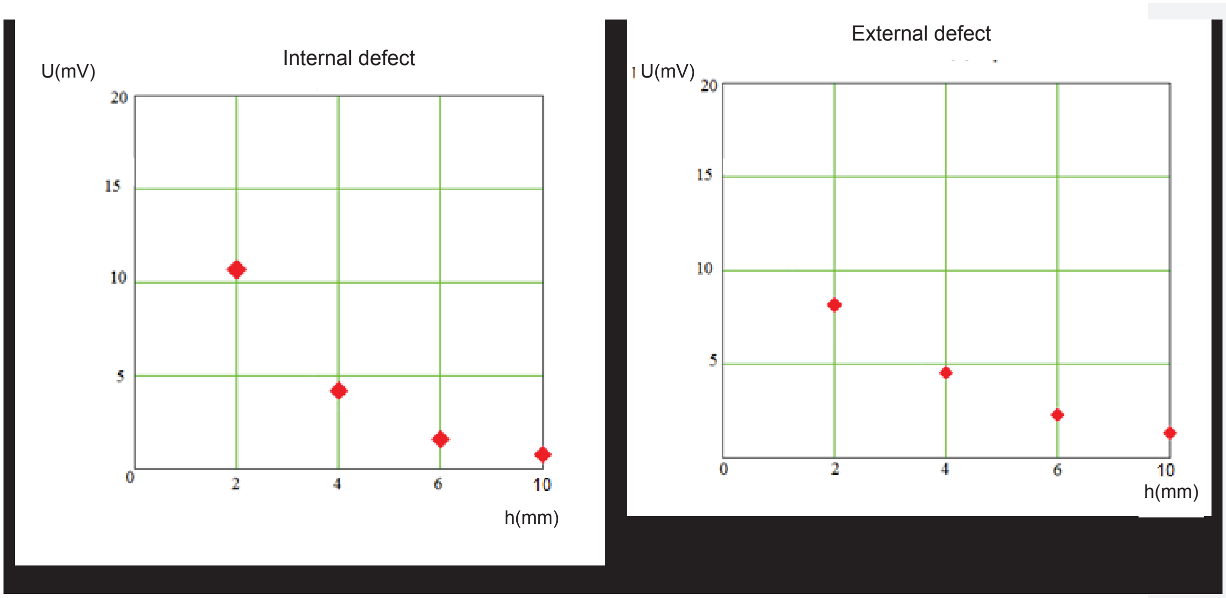


**Figure 8.** Sensor voltage amplitude versus pipe wall loss.

subsurface pipelines of small-diameter heating networks (DN200, DN400) without pipeline break in the energy and utilities area", Unique identifier of Applied Research and Advanced Developments RFMEFI58114X0004 in the ITMO University.

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