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INFLUENCE OF THE PIPE DEFECT ON ITS MAGNETIC FIELD

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The components of the magnetic field of a steel pipe, which is described by the field of a dipole thread, are considered. The calculated model of the pipe field with a defect is constructed. The quantitative results of calculations of deformation distributions of field components caused by various defects and for various orientations of the primary excitation field are presented and analyzed.

It is shown that the normal (radial) component of the deformed magnetic field is 5 times greater than the tangential (azimuthal) component.

The obtained results can be used to assess the capabilities and development of methods and means for remote detection and determination of defects parameters of the steel pipe.

Keywords: *pipe defect, magnetic field, calculation model, field distribution.*

ВПЛИВ ДЕФЕКТА ТРУБИ НА ЇЇ МАГНІТНЕ ПОЛЕ

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Розглянуто компоненти дипольного магнітного поля сталевої труби. Описано розрахункову модель поля труби з дефектом. Наведено і проаналізовано кількісні результати розрахунків залежностей деформацій розподілу компонент поля, спричинених різними дефектами за різних орієнтацій первинного поля збудження.

Показано, що нормальна (радіальна) компонента деформованого дефектом магнітного поля в середньому у 5 разів більша від тангенціальної (азимутальної) компоненти.

Отримані результати можна використати для оцінки можливостей та розроблення методів і засобів дистанційного виявлення і визначення параметрів дефектів сталевої труби.

Ключові слова: *дефект труби, магнітне поле, розрахункова модель, розподіл поля.*

Introduction. Informative signs of the influence of defects on characteristics of physical fields are necessary for creation of facilities and development of technology for monitoring and diagnostics of technical state of the objects to prevent their damage and to continue trouble-free operation [1].

Magnetic methods are used to diagnose the state of the wall of the pipelines and reservoirs [1–4]. Magnetic Flux Leakage (MFL) method (method of dispersed magnetic flux) consists in magnetizing the area of the control object (CO) and fixing magnetic field (MF) scattering that occurs above the surface in the presence of defects or decrease of the thickness of the CO. The MFL method is one of the main in non-destructive testing for detecting mechanical and corrosion damages in pipelines. For internal defectoscopy pig-defectoscopes are used. They are able to detect damage caused by both electrochemical and microbiological corrosion and corrosion cracking under tension.

Among the contact methods the method of magnetic memory is an effective one. It uses specialized magnitometric instruments as tension concentration meters and applies MF sensors. Control does not require pre-surface preparation. In some cases testing of the pipelines metal wall can be carried out without removing the insulation.

Disadvantages of these methods are: significant influence of the distance between the MF sensor and the CO surface on the sensor signal, the lack of information about the depth of defects occurrence and significant increase of the dimensions and weight of equipment for testing of the objects with a wall thickness of more than 16 mm [2]. The main technological disadvantage of the contact diagnostics methods is the need for access to the pipeline. They can be used for overhead pipelines, relative amount of which is not large, and for pipelines, which are prepared for stacking in a trench.

Remote methods are promising ones for diagnostics of underground and underwater pipelines (UP). Non-contact measurements of alternating magnetic field of cathodic protection or current generator [1] are able to detect the placement and the depth of occurrence of pipeline, to control the state of anticorrosion protection (insulation and cathodic polarization), to evaluate the parameters and to detect the damages of insulation and the location of corrosion. The method of magnetic gradientometry may be used to detect the UP areas with different locations of the welds, defects of UP geometry and the stress-strain state [5]. It is based on established links between these characteristics of the steel UP and the distribution of its MF. The components and gradient of MF are measured by magnetometer-gradientometer. Specialized magnetometer is manufactured in the form of portable devices and can be used to testing the magnetic fields of various types of pipelines. Therefore, these methods are considerably faster, suitable for express control and more effective than the intrinsic and contact methods.

The subject of this paper is the theoretical study of the influence of defect of the steel pipe on the distribution of its magnetic field.

Magnetic field of the pipe. Let a cylindrical pipe with an external radius R and thickness T and relative magnetic permeability of material μ be located in constant homogeneous magnetic field H_0 perpendicular to the axis of the pipe and inclined at an angle φ relative to the vertical. In this case the magnetic field is described by the gradient of the scalar potential U [6, 7]. In a cylindrical coordinate system (r, φ) with an axis aligned along the axis of the pipe, the scalar magnetic potential of the primary field is $U_0 = H_0 r\cos\varphi$. The secondary field $\vec{H} = -\mathrm{grad}U$, where $U(r, \varphi)$ is the solution of the Laplace equation and satisfies the corresponding boundary conditions [7]. For the components of the MF in the outer region of the cylinder $r \geq R$ we obtain the formulas [8, 9]

$$H_r = -H_0\left(1 + \frac{R^2}{r^2}M\right)\cos\varphi, \tag{1}$$

$$H_\varphi = H_0\left(1 - \frac{R^2}{r^2}M\right)\sin\varphi, \tag{2}$$

where $M = (1-t)(\mu^2 - 1)\Big/\Big[(\mu+1)^2 - t(\mu-1)^2\Big]$, $t = ((R - T / R)^2$.

The second parts in formulas (1) and (2) describe the secondary MF, which has a dipole character. It is convenient to represent it in a vector form as a field of “dipole thread” [9, 10]:

$$\vec{H}_2 = \frac{m}{2\pi\mu r^2}\left(\vec{r}_0 \cos\varphi + \vec{\varphi}_0 \sin\varphi\right). \tag{3}$$

Each point of such a thread is a transversely oriented dipole; m – absolute value of the dipole moment per unit length. For a cylindrical tube the equivalent magnetic moment [9]

$$m = 2\pi R^2 \frac{(1-t)\left(\mu^2-1\right)}{(\mu+1)^2 - t(\mu-1)^2}\mu H_0 . \quad (4)$$

Fig. 1 shows a cylindrical tube in the primary homogeneous magnetic field $\boldsymbol{H}_0$ and the power lines of its secondary dipole field $\boldsymbol{H}_2$.

The performed calculations and experimental measurements on the tracks of the main gas pipelines showed that the secondary field of the pipe magnetization was essentially heterogeneous and its presence was to be taken into account during non-contact measurements of the direct current [9, 11–13].

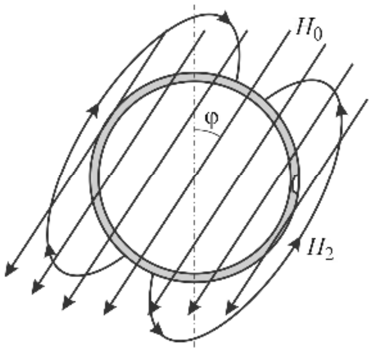

Fig. 1. Pipe with a defect in homogeneous magnetic field $\boldsymbol{H}_0$ and power lines of the secondary dipole field $\boldsymbol{H}_2$.

The magnetic fields of defects in the form of violation of the continuity of the ferromagnetic material are investigated using various models [1, 2, 9, 14–17]. Longitudinal or local defects are presented as tapes, screens, wedges, spheres. Sometimes, instead of a defect, a certain magnetic charge is assigned and the components of the MF, which it creates in the material medium or over its surface of CO, are calculated.

In this paper we use the Finite Element Method Magnetics (FEMM) computer program – a set of programs for solving low-frequency electromagnetic (including magneto-static) problems in two-dimensional planar and axisymmetric regions using the finite element method.

The calculation model is shown in Fig. 2. To calculate the influence of the pipe defect on the distribution of its MF, a typical cylindrical steel pipe was chosen: with outer diameter $D = 2R = 325$ mm, wall thickness $T = 10$ mm, relative magnetic permeability of the steel $\mu_T = 200$ and medium $\mu_s = 1$. The defect is modeled by a cut of width d and depth b in the pipe wall, $\varphi_d = 90°$. The pipe is located in the field of the excitation coil, which consists of two parts of the copper winding: the upper – 500 and the bottom – + 500 turns; current – 1 A. Cross-section of the winding is 50×10 cm. The distance of each part of the winding from the pipe of 100 cm is chosen so that the primary MF excited in the zone of the pipe was almost homogeneous.

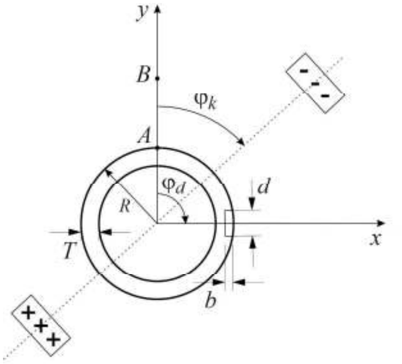

Fig. 2.

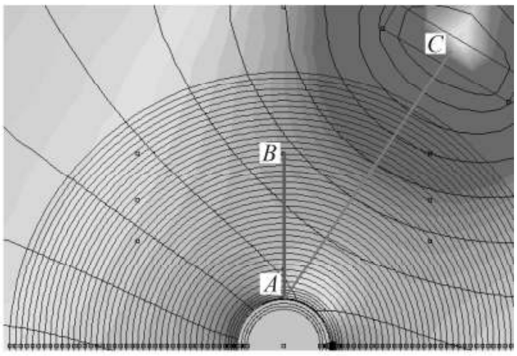

Fig. 3.

Fig. 2. Calculated model of the magnetic field of a tube defect.

Fig. 3. Computer representation of magnetic field excited by current C near a steel pipe.

In the scope of numerical simulation a circle of 250 cm in diameter which covers the pipe and the source of MF (coil windings) is selected. The program splits the region into triangular elements, the size of which is larger in the free space and smaller in the metal CO region and its heterogeneities. For the calculations below, the simulation area was split into 20500 elements.

The orientation of the primary MF was determined by placing the coil windings at different angles φ_k relative to the vertical. Dependences of the MF of a pipe with a defect with dimensions d and b and without defect were calculated along the vertical line AB, which coincided with the axis y. Point A was on the pipe surface and point B was at a distance of 50 cm from point A (Fig. 3).

Results of calculations. To illustrate the influence of the tube defect on its MF, let's give the calculated dependences of the changes of normal (vertical) H_y and tangential (horizontal) H_x of the MF components

$$\Delta H_y(l) = |\, H_y(l)_{\mathrm{def}} - H_y(l)_{\mathrm{nodef}} \,|, \quad \Delta H_x(l) = |\, H_x(l)_{\mathrm{def}} - H_x(l)_{\mathrm{nodef}} \,| \tag{5}$$

with distance l from the pipe surface for different orientations of the primary field and the various dimensions of the defect, shown in Figs. 4–7. The orientation of the primary MF indicates the angle between the direction (azimuth) of the field vector (φ_k + 90°) and the azimuth of the defect (φ_d = 90°). The value of this deviation of the primary MF direction from the defect azimuth is shown in the figures by the corresponding graphs.

Fig. 4 shows the changes of the normal $\Delta H_y(l)$ and tangential $\Delta H_x(l)$ components of the MF, caused by the defect (5), and their dependence on the distance from the pipe with a defect d = 4 mm, b = 10 mm for different directions of the primary MF.

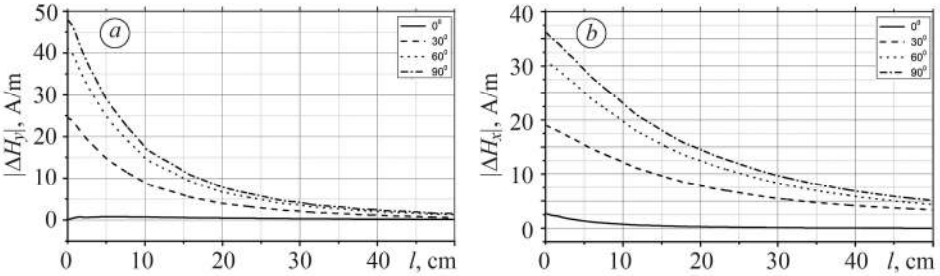

Fig. 4. Changes of the normal $\Delta H_y(l)$ (a) and tangential $\Delta H_x(l)$ (b) components of the MF, caused by the defect (d = 4 mm, b = 10 mm) in a pipe for different directions of the primary MF.

As can be seen from Fig. 4 the influence of the defect on the change of the secondary MF of a pipe is most pronounced when the primary MF is perpendicular to the radial line passing through the middle of the defect, that is, when the angle between the direction (azimuth) of the field vector and the azimuth of the defect is equal to 90°. In this case in Fig. 2 and 3 the primary MF is directed vertically (φ_k = 90°). Then (according to the physics of the phenomenon) MF concentrated in the pipe wall is most scattered by a defect. If the primary MF is directed horizontally (φ_k = 0°), this defect almost does not deform the pipe MF (see solid lines in Fig. 4).

Figs. 5–7 show the results of calculations of relative changes in the pipe MF, caused by different defects dimensions under different orientation of the primary MF, depending on the distance l to the pipe surface;

$$|\, \Delta H(l) \,|, \% = |\, H(l)_{\mathrm{def}} - H(l)_{\mathrm{nodef}} \,| \times 100 \,/\, |\, H(l)_{\mathrm{nodef}} \,|, \%. \tag{6}$$

Figs. 6 and 7 show the results of calculations of the relative changes (6) in the components of the pipe MF caused by the cut-off cut d = 30 mm, b = 10 mm and the defect of the type of corrosion damage (by half of the thickness) of the pipe wall d = 30 mm, b = 5 mm for different orientations of the primary MF.

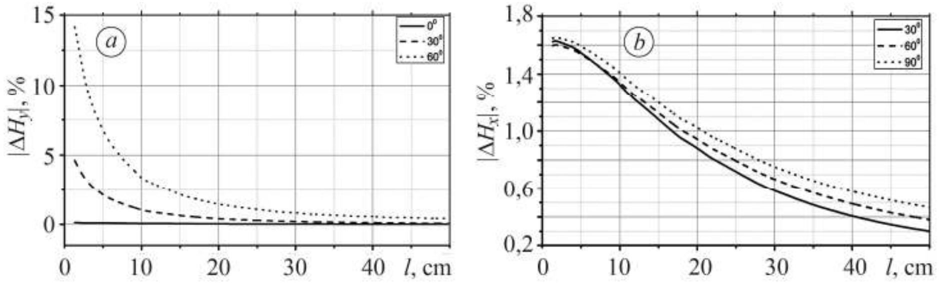

Fig. 5. Relative changes of normal $\Delta H_y(l)$ (*a*) and tangential $\Delta H_x(l)$ (*b*) components of the MF, caused by defect d = 4 mm, b = 10 mm, with distance from the pipe (6) for different directions of the primary MF.

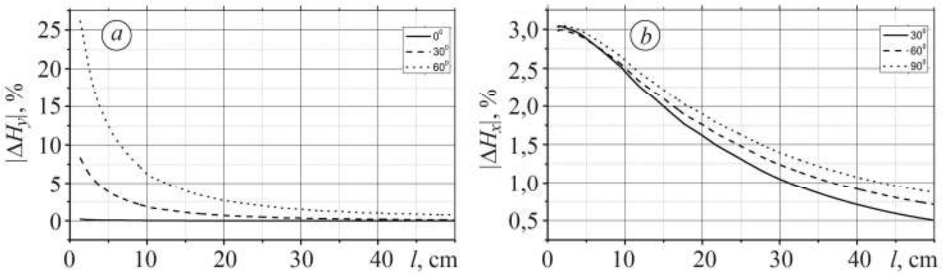

Fig. 6. Relative changes of normal ΔH_y (*a*) and tangential ΔH_x (*b*) of the MF components with distance from the pipe (6) with a defect d = 30 mm, b = 10 mm for different directions of the primary MF.

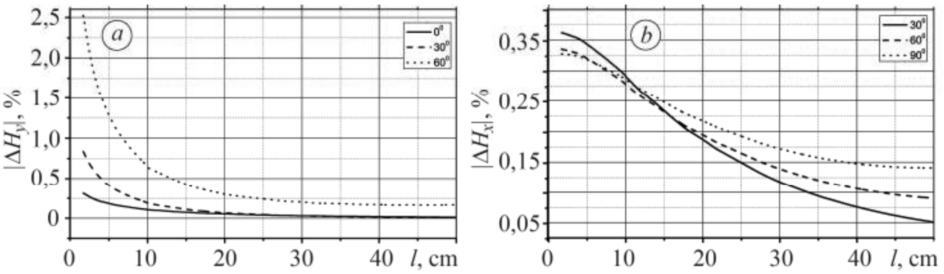

Fig. 7. Relative changes of normal ΔH_y (*a*) and tangential ΔH_x (*b*) components of the MF with distance from the pipe (6) with defect d = 30 mm, b = 5 mm for different directions of the primary MF.

CONCLUSIONS

The given calculation results show that the defect changes the magnetic field of the pipe mostly when it is placed on the path of the magnetic flux and deforms (disperses) it. If the primary magnetic flux is distributed so that the defect is placed at the location of its branching, then the effect of the defect on the distribution of the magnetic field is not manifested.

Quantitative estimates of the dependences of the values of the deformation of the magnetic field on the size of the defect of the pipe wall show that increasing the width of the transverse defect from 4 to 30 mm increases the deformation field by 2 times. A defect with a depth equal to half the thickness of the pipe wall (5 mm) deforms the field by 10 times less than the cut-off defect (10 mm) of the same width.

The resulting deformations of the pipe field with a diameter of 325 mm make up about 25% (from the value of the field of the pipe without defect) at a distance of 1 cm and decrease to 1% and less at a distance of more than 0.5 m from the pipe surface.

Caused by a defect normal (radial) component of the magnetic field is on average 5 times greater than the tangential (azimuthal) component.

The obtained results can be used to assess the capabilities and development of the methods and means for remote detection and determination of the parameters of the steel pipe defects.

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