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ANTIINTERFERENCE DETERMINATION OF UNDERGROUND PIPELINE PLACEMENT

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The protection against interference with methods and means of determining the location of underground cables and pipelines and the main stages of the development of induction track finders has been analyzed. Theoretically, the informative features of the distribution of the magnetic field differential current conductors for the choice of the difference magnetosensor of small-scale track finders protected from external field are investigated.

It is found that for the difference magnetosensors orthogonal to the base, the profiling function has a maximum signal over the current conductor. For the difference magnetosensors parallel to the base there is a clear minimum of the signal over the current conductor between the two maxima located at a distance equal to the depth of the current conductor. Such differential magnet sensors are suitable for determining the location and depth of the underground pipeline, with the removal of the influence of an external almost homogeneous obstacle-causing magnetic field.

Keywords: *magnetic field, current conductor, profiling functions, difference signs, pipeline, obstacles, trace detector.*

ЗАВАДОСТІЙКЕ ВИЗНАЧЕННЯ РОЗМІЩЕННЯ ПІДЗЕМНОГО ТРУБОПРОВОДУ

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Проаналізовано захищеність від завад методів і засобів визначення розміщення підземних кабелів і трубопроводів та розвиток індукційних трасошукачів. Теоретично досліджено інформативні ознаки розподілу диференціалів магнітного поля струмопроводу для вибору різницевих магнітосприймачів малогабаритних завадозахищених трасошукачів.

Виявлено, що для різницевих ортогональних базі магнітосприймачів функція профілювання має максимум сигналу над струмопроводом. Для різницевих паралельних базі магнітосприймачів є чіткий мінімум сигналу над струмопроводом між двома максимумами, віддаленими один від одного на відстань, рівну глибині залягання струмопроводу. Такі різницеві магнітосприймачі придатні для визначення як місця, так і глибини залягання підземного трубопроводу з вилученням впливу стороннього майже однорідного заводонесучого магнітного поля.

Ключові слова: *магнітне поле, стумопровід, функції профілювання, різницеві ознаки, трубопровід, завади, трасошукач.*

The needs of detection and placement of underground pipelines and cables appeare right after their construction [1–3]. It is important because there is a risk to damage communications during soil excavation. The cost of underground pipelines reparation is much higher than their initial installation. It includes expenses on repair of the damage, topsoil and earth excavation, service equipment, works on the compilation of reports and claims for damages. Every damage deteriorates the characteristics and integrity of the underground pipeline or cable system. Public losses are the most important. Deficiency of water, energy or problems with communications can paralyze society. Damaged pipeline or cable is a cause of serious danger, which can lead to disaster, mutilation or personnel deaths. It most often happens because of the existence of flaws or corrosion and damages during works, when the placement of pipelines and cables is not known. Information about their existence and placement helps to avoid the possibility of involvement. However, usage of schemes, drawings or directive route signs is not enough. Widespread use and improvement of track finders is an actual and practically important task.

The **purpose** of this paper is to analyze the operational characteristics and anti-interference methods and means of determining the location of underground cables and pipelines, an overview of the main stages of the development of the induction track finders and the **theoretical study** of informative features of the distribution of magnetic field differential of current conductors in order to select the difference magnet sensors to create small-scale protected track locators.

Below there is a list of the most popular methods and ways of detection and tracing of the underground cables and pipelines [2].

- Analysis of documentation. Schemes and drawings, which are owned by services and administrations, contain a lot of information about underground pipelines and cables. For examination of the location it is important to get all available documentation. Most often information is incomplete but it can be a starting point for an operator. For the beginning of work any information can be useful even when it allows us to find placement only roughly. In this method, the main obstacles are changes (replanning or reconstruction) of locality or object.
- Ground-penetrating radar is a geophysical device, that uses radio-locator to explore the subsurface. It consists of transmission and receiving antennas and blocks of registration and control. It can detect underground objects and measure their size using electromagnetic waves. Therefore, it is good for the location of underground objects, separate plastic pipelines and fiber optic communication channels. However, this device can't exactly distinguish plastic pipes with water from dense damp soil. High conductance of the soil, groundwaters, and inhomogeneities which dissipate a signal are the main obstacles. Also, radar information is very complicated and only a highly skilled specialist can understand it. Consequently the use of this method in everyday work is inexpedient. Still this method will be used for drafting schemes of underground objects.
- Acoustic methods are used for search of water leaks from underground pipelines and tracing underground water pipes, especially of plastic pipelines. Further development can expand the scope of application, in particular for tracking the underground plastic gas pipes.
- Infrared thermography can be an effective method of location of underground pipelines and cables if their temperature is different from the temperature of a medium, soil. But the effectiveness of this method depends on surrounding conditions and it decreases because of sunlight or wind. In practice these methods have a narrow scope of application, e.g. in: a search of cavities in sewer collectors and location of ruptures, cracks, and damages of an insulating surface on the section of insulated pipes.
- Dowsing is the oldest method of location of water and underground pipelines. Dowsers use tree branch or osier; sometimes, they can use welding electrodes, etc. This interesting way requires specific skills and intuition, which limit its wide usage, despite the simplicity of equipment.
- Electromagnetic location is multipurpose and the most common method of search and tracing of the underground objects. This method allows getting more information than other technologies. It has such distinctive features as:

– a search of borders of pipelines and cables from the surface;

– tracing and identification of certain lines;

– tracing and identification of sewer collectors or other non-metallic channels and pipes; localization of obstruction and damages (using miniature plug-in transmitter-probe);

– measurement of the depth of occurrence;

– portability and light weight of equipment; possibility of its use by non-experienced operators;

– possibility to use for different soils and under water;

– a low price of equipment and its parts; possibility of purchase by small organizations and contract firms.

– An electromagnetic method can be also applied for diagnostic examinations and testing of anti-corrosion protection and search of damages of underground and underwater pipelines [1, 4].

Effect of electromagnetic induction, discovered by Michael Faraday, is most often used for the detection and tracking of underground pipelines [3–9]. Method of electromagnetic induction for the location of underground pipelines was applied for the first time in 1910 [3]. One of the first cable route finder, made from cable coiled on a wooden frame, is shown on the photo (Photo 1).

Smaller searching devices were designed by American and German track finder schools in following years. In the middle of the 20th century, as results of researches of detection of location accuracy, Bell Labs (USA) and Electrolocation (England) designed locators with two inductors which were able to measure a depth of a cable occurrence [2]; similar devices were designed in the USSR, in Ukraine [2, 3].

The main feature of such trace detectors is the placement of an induction magnet detector at a distance from the amplification unit in order to reduce their mutual influence. This was achieved with the help of a rod, at the end of which the coil (sensor of the signal) was fixed [3, 5, 9]. This allowed the easier search, but it also led to significant influence of electrical interference from power lines on track finder and greatly complicated the definition of the location of underground communications near the transmission lines (with which they are often located in one corridor). Except this, the devices for measurement of the depth of occurrence used two sensors placed at a distance, which was commensurable with the distance to the object [5–8]. This caused the increasing size of the devices and problems of working on the traces.

Photo 1. One of the first locators to search underground communications, 1910.

The first **portable track finder** of ORT type for non-contact determination of location, direction and depth of occurrence of underground pipelines and other hidden conduit communications was created thanks to the proposed placement of the magneto-sensor and elements of the amplifier block in a small-sized case [1, 8, 10]. This successful technical solution made it possible (in addition to the efficient track finders) to develop the following complex two-functional portable device ORT+V for contactless determination of the location and contact measurements of the potential of underground pipelines [8, 11] (see Photo 2).

Photo 2. Portable track finder with voltmeter ORT+V.

The ORT device can be used to remotely control the operation of cathode protection (UCP) installations from corrosion of underground metal structures. The device operates in the zone of action of the UCP, or in the zone of action of the additional current generator. The device is designed to work in field conditions on the lines of main oil and gas pipelines and other conductive communications. ORT+V is functionally assembled in a small enclosure, without additional antennas, headphones; it is very easy to operate (there is only one switch). An indication is visual. In the search mode an operator rotates and moves the device and sees signal changes on the indicator. Operator finds the orientation of the device when the signal has maximum and minimum [8] and based on this information determines the placement of an object (current conductor). In voltmeter mode the measured value is displayed on the digital indicator. Advantages of the device – small weight and dimensions, ease of use, sufficient precision, a layout of the two necessary devices in one case – contribute to the increased efficiency and performance of work on the pipelines.

Due to the small dimensions of the ORT device it does not have an element of the electric antenna type. Therefore, ORT is protected from the influence of the electric field of power lines. ORT works on underground pipelines in the zone of action of the UCP without connection to the pipe and the ground, regardless of the state of the soil surface. However, two or more pipelines and cables are often laid in one corridor, which are protected by a single UCP. Different distributions of currents between communications are possible. The line in which the larger current flows creates bigger obstacles for surveys of other communications [12]. Then, in absolute measurements of the magnetic field of the alternate component of the current UCP, the definition of the location of different pipelines is complicated.

In addition to the known frequency filtering, to resist interference the spatial distributions of the field are used. The field of disturbance of a remote third-party source can be considered homogeneous (if its changes in the control zone are much less than the changes of the field of the object under the test). Then effective metering methods are available, which enable to eliminate the effect of a third-party homogeneous field of interference. The **difference methods** of measurement of the alternating magnetic field are used in the development of equipment such as UGRI, IMK-5, BVC-2 [1, 8, 13–15] for surveying underground pipelines. In order to improve the accuracy of measurements of the depth and the current of the underground pipeline in these (and similar) devices, the length of the base *b* – the distance between the magnet sensors was taken dimensionally (0,6 ... 1 m) with the depth of the pipeline occurrence *h*. But the increase of the base (in addition to the unwanted increase in the dimensions of the device) leads to an increase in the impact of interference from the third-party sources that are not sufficiently distant (other communications).

Theory. In order to select the optimal difference magnet sensors for the creation of a small-size blockade of a protected track finder, we investigate the dependences of the profiling functions of the distribution of the magnetic field of the rectilinear current on the direction of differentiation. Calculate the dependence of the signal of the difference magnet sensors on moving across the line of the current line under their different orientations.

The magnetic field of the current flowing along the cylindrical tube is equivalent to the field of linear current flowing along the axis of the pipe and is determined by the formula $H_\phi = J / 2\pi r$, where J is the current, r is the distance from the center of the pipe to the observation point beyond its limits [8] as shown in Fig. 1. Designing H_ϕ on the axis of the abscissa and ordinates, taking into account that $r = \sqrt{x^2 + y^2}$, we obtain its horizontal and vertical components:

$$H_x = \frac{J}{2\pi}\frac{y}{x^2 + y^2}, \quad H_y = \frac{J}{2\pi}\frac{x}{x^2 + y^2}. \tag{1}$$

Consider two possible variants of the arrangement of differential sensors, with the sensitivity axes orthogonal *a* and parallel *b* to the base, shown in Fig. 2. In addition, consider possible different variants of orientation of the magnetosensors base during their movement across the route for the search of the underground pipeline.

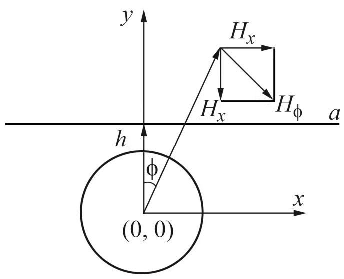

Fig. 1.

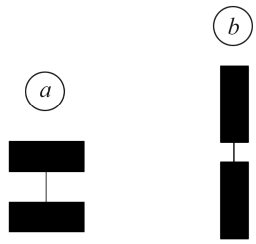

Fig. 2.

Fig. 1. Components of the magnetic field of rectilinear current.

Fig. 2. Differential magnet sensors: orthogonal (*a*) and collinear (*b*) to the base.

The partial derivatives of the components H_x and H_y for x and y have the form:

$$\frac{\partial H_x}{\partial x} = -\frac{J}{2\pi}\frac{xy}{(x^2 + y^2)^2}, \quad \frac{\partial H_y}{\partial y} = -\frac{J}{2\pi}\frac{xy}{(x^2 + y^2)^2}, \tag{2}$$

$$\frac{\partial H_x}{\partial y} = \frac{J}{2\pi}\frac{x^2 - y^2}{(x^2 + y^2)^2}, \quad \frac{\partial H_y}{\partial x} = \frac{J}{2\pi}\frac{y^2 - x^2}{(x^2 + y^2)^2}. \tag{3}$$

The difference in the signals of the named pairs of magnet sensors in the horizontal Δx or in the vertical Δy of the base orientations is written by the formulas for each of these variants, respectively:

$$\Delta_x H_x = H_x(x + b,\ h) - H_x(x,\ h) = \frac{J}{2\pi}\left(\frac{h}{(x+b)^2 + h^2} - \frac{h}{x^2 + h^2}\right), \tag{4}$$

$$\Delta_y H_y = H_y(x,\, h+b) - H_y(x,\, h) = \frac{J}{2\pi}\left(\frac{x}{x^2+(h+b)^2} - \frac{x}{x^2+h^2}\right), \qquad (5)$$

$$\Delta_x H_y = H_y(x+b,\, h) - H_y(x,\, h) = \frac{J}{2\pi}\left(\frac{x+b}{(x+b)^2+h^2} - \frac{x}{x^2+h^2}\right), \qquad (6)$$

$$\Delta_y H_x = H_x(x,\, h+b) - H_x(x,\, h) = \frac{J}{2\pi}\left(\frac{h+b}{x^2+(h+b)^2} - \frac{h}{x^2+h^2}\right). \qquad (7)$$

Calculations of the values of the profiling functions on the interval of the abscissa axis from –7 to 7 m were obtained by the given formulas at $J = 2\pi$ A, $h = 1$ m and $b = 0.1h$. The dependences of signals on the displacement of magnet sensors across the line are shown in Figs. 3–5.

As can be seen from formulas (2), the partial derivative components H_x and H_y are the same in their directions (dx and dy). In Fig. 3*a* dependences coincide. The corresponding derivatives of the orthogonal directions by formulas (3) have opposite signs (Fig. 3*b* shows only the dependence of the derivative dH_y/dx on $-7 < x < 7$; the dependence of the derivative dH_x/dy is distinguished by a sign).

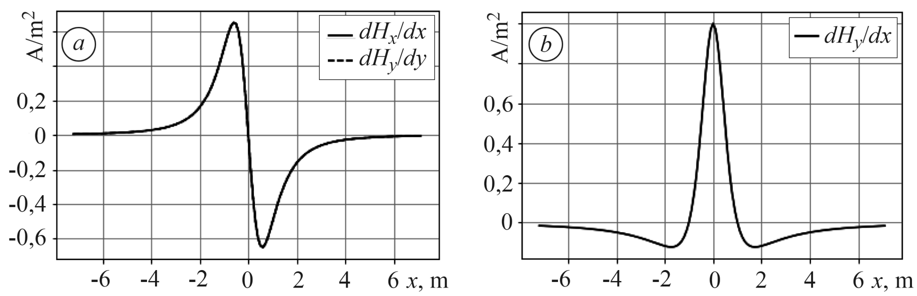

Fig. 3. Profiling functions across the pipeline of the differential of the magnetic field components in their (*a*) and orthogonal (*b*) directions.

Fig. 4 shows differences in the components of the magnetic field and their modules as profiling functions across the line of differential signals (Fig. 4*c*) from the parallel base of horizontal (Fig. 4*a*) and vertical (Fig. 4*b*) magnetosensors.

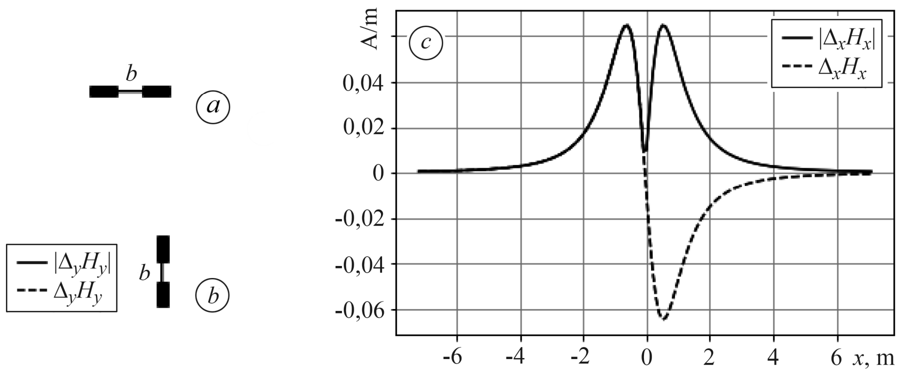

Fig. 4. Parallel to base horizontal (*a*) and vertical (*b*) differencial magnet sensors, and profiling functions (*c*) of the differences of the magnetic field components.

Fig. 5 shows differences in the components of the magnetic field and their modules as profiling functions (Fig. 5*b*, *d*) across the current conduktor of differential signals from the orthogonal base of the horizontal (Fig. 5*a*) and the vertical (Fig. 5*c*) magnet sensors.

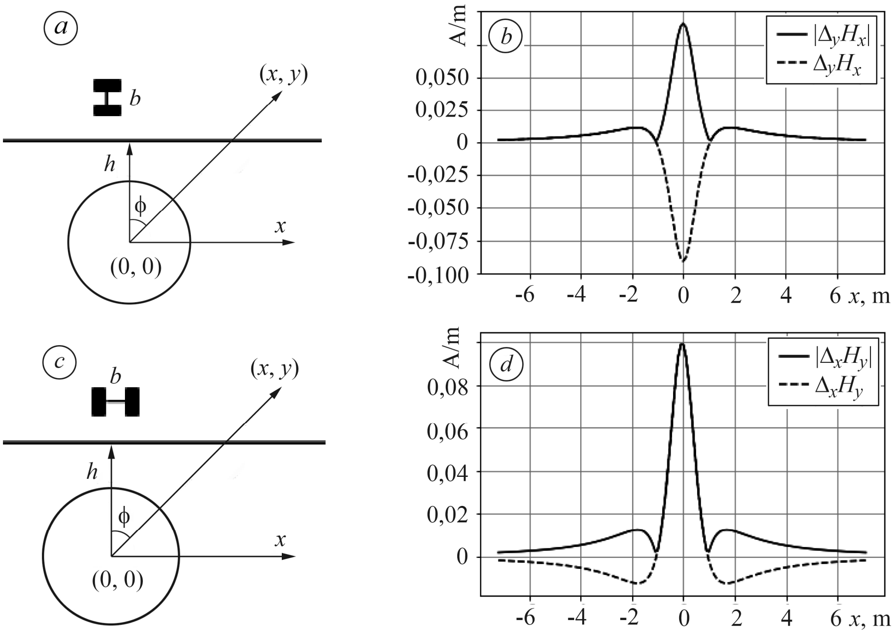

Fig. 5. Profiling functions (*b*) and (*d*) of difference between the horizontal (*a*) and the vertical (*c*) components of the magnetic field orthogonal to the base and their modules (signals) across the line.

CONCLUSIONS

From the above results of calculations it is seen that the use of the difference orthogonal base of horizontal (Fig. 5*a*) and vertical (Fig. 5*c*) magnet sensors shows clearly expressed maxima of the signal over the current conductor. At both ends there are shallow minima of the signal, far from the maximum at a distance equal to the depth of the current line.

In contrast to this, the use of the difference in the **parallel** base of the horizontal (Fig. 4*a*) and the vertical (Fig. 4*b*) magnet sensors shows a clearly expressed minimum of the signal over the current conductor between the two signal maxima. Since these maxima are sharp and are spaced apart at a distance equal to the depth of the current conductor, these differential magnet sensors are more suitable for determining both the location and the depth of the occurrence of the underground pipeline, with the removal of the influence of an external almost homogeneous interfering magnetic field.

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