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Physıcal characterıstıcs of the Hall effect and possıbılıtıes of applıcatıon of galvanometrıc transducers and sensors desıgned on ıts basıs ın defectoscopy

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Abstract: The efficient exploitation of hydrocarbon deposits is based on ensuring the stable operation of the equipment used in each of the fields of drilling wells, extraction of resources, processing, storage and transportation. In the article, it was noted that the efficient exploitation of hydrocarbon deposits is related to the essence of the technical and technological issues used in the relevant practice and the possibilities of solving them by efficient methods. the features of use of galvano-nomagnetic converters and sensors designed based on the effect in solving actual practical issues such as defectoscopy are explained.

Keywords: Exploitation of hydrocarbon resources, Hall effect, Galvanomagnetic transducers and sensors, Defectoscopy.

1. INTRODUCTİON

The process of assimilation of resources of hydrocarbon deposits is realized as a result of multifaceted activities carried out in the necessary directions related to each other, such as drilling wells, extraction of resources, processing, storage and transportation. The efficiency of this process is largely determined by the reliability of the technical and technological solutions used. The reliability of the mentioned technical and technological solutions, in turn, is made possible by ensuring the stable operation of the equipment used in each of the areas of drilling wells, extraction of reserves, processing, storage and transportation. Currently, non-disruptive control methods are used for the operation of equipment with a wide spectrum in the mentioned subfields of the oil and gas industry. In this regard, the characteristics of the use of galvanomagnetic transducers and sensors designed on the basis of the Hall effect in solving many practical issues in the fields listed in the article, as well as in defectoscopy (detection of defects) are explained. In the article, a special place is given to the disclosure of the content of the Hall effect and the explanation of its physical and quantitative properties.

As mentioned, the effective implementation of the process of exploitation of the reserves of hydrocarbon deposits is based on ensuring the stable operation of the equipment used in each of the fields of drilling wells, extraction of resources, processing, storage and transportation. Investigating the issues of ensuring the stable operation of the equipment used in these fields has always attracted the attention of researchers as an actual scientific-practical issue. So, currently, non-destructive control methods are used for the durability of many materials with specific application conditions due to the relevant research conducted in the mentioned areas of the oil and gas industry. These research works are currently being carried out on a wide spectrum.

The main direction of these studies is the creation of effective non-destructive control methods for the durability of materials based on various physical effects. Let's take a look at some of these research studies. Thus, the work of [1] is devoted to one of today's current trends - the research and use of galvanomagnetic converters in the detection of defects in oilfield machines and equipment, and it is noted that one of the main issues in the design technology of oilfield equipment is its hidden critical defects. related to the identification of parts. It was shown in [2] that a potential difference in a non-homogeneous magnetic field is created on the presence of electrodes placed in a ferromagnetic suspension used in the detection of defects of magnetic particles. This phenomenon can be used to trace defects in ferromagnetic products. In [3], the results of numerical modeling and experimental research on the possibilities of using the simultaneous magnetization of a ferromagnetic product with strong constant and weak alternating fields to determine the possibilities of increasing the reliability of the detection of magnetic defects of main gas pipelines, in particular, for the detection of stress-corrosion damage, were presented. In the work of [4], focusing on the creation of equipment for detecting defects in products made of ferromagnetic materials, in particular, the necessity of creating a defectoscope (defect detector) for pipelines was mentioned, in this regard, high efficiency and reliability are mentioned in the literature for detecting defects. an approach based on the Hall effect, known and described as the effect of In the article [5], the theoretical justification of the Hall effect was presented and its practical application possibilities were discussed.

2. EXPERIMENT DETAİLS

Galvanomagnetic converters are based on the physical effects that occur when charged particles move in solid bodies located in a magnetic field. As measuring transducers, semiconductor galvanomagnetic transducers based mainly on the use of Hall and Gauss effects have found practical use. The Hall effect consists of the creation of a transverse potential difference (Hall electric motive force) on the sides of the plate (picture), while the Gaussian effect or magnetoresistive effect manifests itself in the change of the electrical resistance of the plate. Both effects are caused by changes in the trajectory of charged particles in a magnetic field, occur simultaneously, and are interconnected in such a way that each weakens the other. By specifically choosing the transducer design and material, one of the effects can be amplified and the other attenuated, thus creating Hall transducers or magnetoresistive transducers. With the help of the Hall effect, when the nature of charge and conductivity of charge carriers is known, it is possible to obtain information about the concentration of free charge carriers, as well as the energy spectrum of charge carriers. This effect, used in defectoscopy, involves the detection of magnetic fields using Hall transducers.

A Hall transducer is usually a four-output device made of a thin plate or film of semiconductor material. Let's take a look at the constructive and some physical characteristics of Hall converters.

Under the influence of Lorentz forces F=evB in the magnetic field, the charge carriers change their trajectory, as a result, the concentration of charges of the same sign on one of the faces of the plate increases and decreases on the opposite side. The difference of the potentials created at this time is determined by the expression.

$$E_{\mathrm{H}} = R_{\mathrm{H}}\varphi(K,\theta) IB\cos\alpha / d \;,$$

Here R_{H} – the Hall constant from the properties of the transducer material; $\varphi(K, \theta)$ – function that depends on the quantity θ between the current density and the voltage vectors caused by the electric field determined by the geometry of the converter and the mobility of the charge carriers and the value of the magnetic induction and the Hall angle θ; α – the angle between the magnetic induction vector and the magnetic axis of the converter and in the first approximation coincides with the normal of the plane of the converter; d – is the thickness of the board.

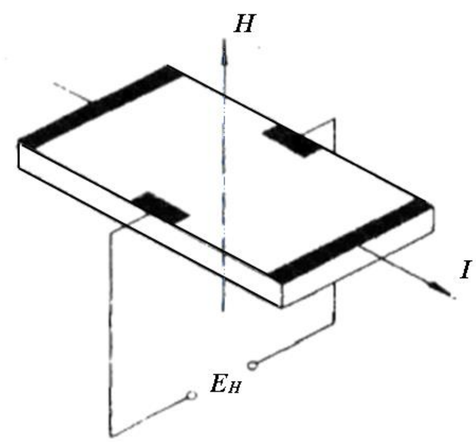

Fig.1. Hall converter: I - control current force; H - voltage vector of the external transverse magnetic field; EH - Hall electromotive force.

The Hall effect manifests itself especially in semiconductors consisting of germanium, silicon, and elements of groups III and V of the periodic system. The Hall constant takes values of 10^{-2} – 10^{-4} $m^3/(A\cdot sec)$ for semiconductor materials, and $6\cdot10^{-11}$ $m^3/(A\cdot sec)$ for pure metals, for example copper.

Crystalline Hall converters are made in the form of thin plates with a diameter of d=0.01–0.2 mm by cutting them from single crystals and bringing them to the required thickness by polishing. Outlets are fixed on the side faces by soldering or welding.

Film Hall converters made of thin polycrystalline films of InAs and InSb on glass substrates and converters based on heteroepitaxial structures of InSb and GaAs on semi-insulating gallium arsenide substrates have good metrological properties.

The sensitive element of the transducer is made in the form of a thin layer (5-10 μm) using the photolithography method. Such transducers can be made in complex shapes with a small area of the sensitive zone (0.2x0.05 mm or less).

The output value of the Hall converter is proportional to two input quantities, namely current I and magnetic induction B. At constant values of these quantities, the Hall electromotive force also takes constant values. If only one of those quantities is constant, the Hall electromotive force is also at the frequency of that variable quantity. If both quantities are shifted in phase by an angle φ with the same frequency, then the Hall electromotive force can be composed of fixed and double-frequency variable limits defined as follows:

$$E_{\text{H}} = \frac{R_{\text{H}}}{d} BI \cos\varphi + \frac{R_{\text{H}}}{d} BI \cos(2\omega t + \varphi).$$

If the current varies with the frequency ω_1, and the magnetic induction with the frequency ω_2, then the Hall electromotive force consists of two components, one characterized by the frequency $\omega_1 - \omega_2$ and the other by the frequency $\omega_1 + \omega_2$.

The input resistance R_{GH} of the Hall converter is determined by the resistance between the current electrodes, and the output resistance R_{CH} is equal to the resistance between the Hall electrodes. In mass-produced Hall converters, the value of these resistances ranges from 0.5 Ohm to several kilohms. As a result of the magnetic resistance effect, the R_{GH} and R_{CH} quantities increase as the magnetic induction increases.

When $\alpha = 0$, it is calculated by the expression of the galvanomagnetic sensitivity of the Hall converter.

$$S_{BI} = E_{\text{H}} / (BI) = R_{\text{H}} \varphi(K, \theta) / d$$

It is 0.3–10 V/(A·Tl) for different types of converters. The magnetic induction sensitivity S_B is defined as a constant value of the nominal input current $S_B = R_{\text{H}} I_{\text{nom}} \varphi / d$. In series-produced Hall converters, the sensitivity to magnetic induction is 0.03–1 V/Tl. The nominal input current value is limited by the allowable heating temperature of the converter. For high-resistance converters, the permissible current value is 5-50 mA, and for low-resistance converters, it is 100-200 mA. Both sensitivity indicators (S_{BI} and S_B) depend on the magnetic induction B, so that $R_{\text{H}} = f_1(B)$ и $\varphi = f_2(B)$. The current sensitivity quantity S_I is defined as the constant value of the magnetic induction B, $S_I = R_{\text{H}} B \varphi / d$. Current sensitivity at magnetic induction equal to B=1 Tl is 0.3–50 V/A for different types of converters. The converter and sensors of the same name created based on the Hall effect are used in practice as a component of non-magnetic control methods. Defectoscopy (detection of defects) is a field of knowledge that includes the theory, methods and technical means of identifying defects in controlled object material, especially in the material of machine parts and elements of metal structures. As a result of non-improved production technology or working in harsh conditions, various defects in technical means (materials) - violation of the durability or homogeneity of the material, deviations from the specified chemical composition or structure, as well as from the specified dimensions. Defects change the material's physical properties (density, electrical conductivity, magnetism, elastic properties, etc.). One of the most important areas of quality control at the stages of production, testing and operation of products is non-destructive testing methods. Every year, the most developed countries spend a large amount of money on the production of equipment for non-destructive testing methods. The main task of non-destructive control of the quality of manufactured products is to use effective control methods and tools, timely detection of technical defects in products during production and use, determination of their causes, and development of measures to ensure proper production and continuous operation [6].

Current methods of defectoscopy of materials include X-rays, infrared, ultraviolet and gamma rays, radio waves, ultrasonic vibrations, magnetic and electrostatic fields, etc. based on the study of its physical properties when exposed to the influence.

Modern drilling and oilfield equipment is characterized by a wide variety of components, equipment and tools and provides various operations for drilling and operating wells. The efficiency of these operations is directly related to the timely detection of defects in the materials of that equipment and the ability to correctly implement the fight against it. For example, it can be noted that the economic indicators of oil production are mainly determined by the reliability and service life of individual assemblies and parts of oil equipment. One of the main elements of oil equipment is the rod well pumps, which, as a rule, have a longer service life than those used in fountain and compressor operating methods. Productivity of rod well pump units is mainly determined by their reliability and service life. Therefore, special requirements are placed on their production [1]. In this regard, it is interesting to study the possibilities of using Hall converters based on the galvanomagnetic phenomenon. This method is mainly used in the determination of surface and subsurface defects in materials in fairly wide temperature ranges. In many cases, Hall sensors based on the Hall effect, which determines the working principle of Hall converters, are widely used. These sensors are widely used in oil and gas industries. As mentioned, the magnetic control method used in defectoscopy in this case is based on the propagation of the magnetic flux occurring in the zone of surface and subsurface defects in the pipeline. The principle of the method of spreading the magnetic flux is that if there is a defect in the metal in the magnetized part of the pipe, then part of the magnetic flux leaves the pipe wall, that is, the magnetic flux is scattered in the defect, and this condition can be detected by a sensor located at a certain distance from the surface of the pipe. This method best detects defects with transverse dimensions sufficient for the formation of a propagation field in the direction of the magnetization field. Therefore, some defects located longitudinally relative to the direction of the magnetic field or having an opening size or depth insufficient for detection are either not reflected in the magnetogram at all, or the signals from them are difficult to interpret. Changes in wall thickness, structural inhomogeneity, etc. due to local changes in the magnetic properties of the pipe. due to the presence of the resulting magnetic noise, there is a certain threshold value for detecting depth defects, which is generally about 10% of the pipe wall thickness. The pipe wall is magnetized by permanent magnets and flexible magnetic conductive brushes, which in turn transmit the magnetic flux between the magnets and the pipe wall. Determining indicators of the magnetic field of the defect are semiconductor Hall sensors that quantify the tangential component of the magnetic field. The work of these sensors is based on the working principle of Hall converters. Sensors are placed in special blocks that have enough elasticity and flexibility to maintain a constant pressure force. The positioning of the sensors allows them to cover the entire inner circumference of the pipe. The distance between the sensors in the circular direction depends on their total number and the diameter of the pipeline.

3.CONCLUSİON

In the article, the characteristics of the use of Hall effect-based galvanomagnetic converters and sensors with wide application possibilities in various fields of the oil and gas industry in solving practical problems, as well as in defectoscopy (defect detection) are described. It is noted that the process of assimilation of resources of hydrocarbon deposits is realized as a result of multifaceted activities carried out in necessary directions related to each other, such as drilling wells, extraction of resources, processing, storage and transportation. The efficiency of this process is largely determined by the reliability of the technical and technological solutions used. The reliability of the mentioned technical and technological solutions, in turn, is made possible by ensuring the stable operation of the equipment used in each of the areas of drilling wells, extraction of reserves, processing, storage and transportation. Currently, non-disruptive control methods are used for the operation of equipment with a wide spectrum in the mentioned subfields of the oil and gas industry. The converter and sensors of the same name created based on the Hall effect are used in practice as a component of non-magnetic control methods.

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