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System for Detection of the Inhomogeneous Distribution of Magnetic Field Based on Liquid Crystals with Magnetic Nanoparticle

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ABSTRACT

The main objective of this article is to develop the basic technological principles of production of the magneto-sensitive layer based on nematic liquid crystals with magnetic nanoparticles as the main component of the system, which allows obtaining a two-dimensional picture of the inhomogeneous distribution of low-frequency magnetic field and to identify the object creating this field. In work are described physical methods which allow to increase sensitivity and to expand a working frequency range of the magneto-sensitive layer based on such liquid crystals. By us it has been shown, that the time of reorientation of director in oriented liquid crystals with magnetic nanoparticles is less than the analogous reorientation time in nonoriented crystals. In work also it is shown, that to significantly increase the speed of reorientation in a magnetic field of the director of liquid crystals with magnetic nanoparticles is possible if submitting an additional magnetic field with given amplitude. This method allows to increase sensitivity to a magnetic field and to receive parametrical amplification of signals in liquid crystals with magnetic nanoparticles. In the conclusion on the basis of liquid crystals with magnetic nanoparticles the scheme of system of detection of inhomogeneous magnetic field is described.

Keywords : liquid crystals with magnetic nanoparticles; magneto-sensitive layer; low-frequency magnetic field; system of detection of magnetic field.

I. INTRODUCTION

The magnetic field measurement technique is widely uses for the non-destructive flaw detection in the manufacture and operation of metal structures, in thermal power engineering, bridge constructions, mechanical engineering, aircraft construction, rail transport, etc. Similar methods use in devices and systems for the search and recognition of metal objects underground, on and under water.

The advantage of using a low-frequency magnetic field is that non-magnetic materials do practically not absorb it. The absorption coefficient of the magnetic field k is defined as $k = (\omega\mu\gamma / 2)^{1/2}$, where ω is frequency of magnetic field, μ and γ are magnetic permeability and conductivity of the material, respectively [1]. Estimates show that the low-frequency magnetic field at ω<100 Hz is weakened is a little absorbed in a layer of earth by thickness to 1000 m or in the same layer of sea water.

Today, the method of a magnetic field scanning by magnetic sensors in two or three directions is used to inhomogeneous magnetic field detection of an investigated area [2-5]. In the case of the three directions, the magneto-sensitive layer changing the spatial characteristics (under the influence of a magnetic field) is used. For this purpose more often the magnetic powder or magnetic dyes is used [6, 7]. Modern detection systems use a magnetically sensitive layer consising of a considerable quantity of magneto-optical sensors [8].

The basic engineering deficiency of systems detection of magnetic field of the first type is presence of the complex system of scanning. Technical characteristics of systems of the second type are limited by low sensitivity and resolution of a magneto-sensitive layer. All this limits the functionality of the systems described above and increases their size. The technical superiority of our development is that it uses as a magneto-sensitive layer liquid crystals with magnetic particles and the optical polarization method of reading information. The high sensitivity of optical polarization methods of data reading (the magnitude of the rotation angle of the plane of polarization at the level of 0.01 degrees) and the possibility of forming a liquid crystal raster layer with the submicron resolution indicates the prospect of our development.

In the present article we wish to show possibility of construction of system for detection of inhomogeneous distribution of magnetic field based on liquid crystals with magnetic nanoparticles, and also to present results of our researches in this area. We also want to note the main problems and tasks that need to be solved in the development of systems based on liquid crystals, and suggest possible methods for solving them. We hope that these results will be useful to researchers and designers in developing a system for detecting magnetic fields.

Magneto-sensitive layer based on liquid crystals

The liquid crystals are important functional materials for creating optoelectronic elements and devices. The most widely used nematic liquid crystals (NLC). Their practical application is associated with the ordering of molecules and the controlled change of their spatial orientation and the liquid crystal field director under the an applied electric field. The NLC molecular ordering can also occur due to the anisotropic-elastic interphase interaction between the NLC molecules and orienting surface. The molecular ordering and rotation of the director under the applied electric field can occur under the flexoelectric effect or due to anisotropy of the dielectric constant of the NLC. The flexoelectric effect is associated with the distortion of the direction field and it is proportional to a applied electric field strength. The contribution of electric field to free energy of NLC can be estimated as

$$W_E = -f_1(\vec{E}\cdot\vec{n})div(\vec{n}) - f_3[\vec{E}\cdot(\vec{n}\times rot\,\vec{n})] - \frac{\varepsilon_0\varepsilon}{2}\left(\vec{E}\right)^2 \quad (1)$$

Here f_1 and f_3 are flexoelectric coefficients of longitudinal and transverse bending, ε_0 is the universal dielectric constant, $\varepsilon = \varepsilon_{\|} - \varepsilon_{\perp}$, $\varepsilon_{\|}$ and $\varepsilon_{\perp}$ is the values of the dielectric constant along and perpendicular to the NRC molecules. The first two terms in (1) describe the effect of flexoelectric ordering of molecules and its value is proportional to the electric field strength. The third term describes the contribution to the ordering energy of anisotropy of the dielectric constant NLC and its value is proportional to the square of electric field intensity.

The ordering of pure NLCs under the applied magnetic field is observed at very high field strength. This is because NLC molecules are diamagnetic. Therefore, the magnetic field-induced molecular ordering in the NLC occurs due to the anisotropy of the magnetic susceptibility. Introduction of magnetic nanoimpurities in NLCs leads to increasing the efficiency of orientation ordering due to the applied magnetic field influence. Corresponding contribution to the free energy is proportional to the square of the magnetic field strength H and the anisotropy coefficient of magnetic susceptibility χ. Then, magnetic energy density of the NLC can be described through the the liquid crystal director $\vec{n}$ and the magnetic vector-director of magnetic nanoparticles, $\vec{e} = \overrightarrow{M_s} / M_s$, where M_s is the magnetic moment of the particles [6, 7] by the expression

$$W_H = \frac{1}{2}\chi\chi_a(\vec{n}\cdot\vec{H})^2 - fM_s(\vec{e}\cdot\vec{H}) - f\,W(\vec{e}\cdot\vec{n})^2 \;, \quad (2)$$

where f is the ordering function of the anisotropic molecules of the liquid crystal, $\chi_a = \chi_{\|} - \chi_{\perp}$, $\chi_{\|}$ and $\chi_{\perp}$ is is the value of the magnetic susceptibility of the liquid crystal in the direction parallel and perpendicular to the molecule anisotropy axis of its molecule.

The first member шт equation (2) describes the interaction of liquid crystals with an external magnetic field, which is caused by the molecular magnetic susceptibility. The second member in equation (2) describes interaction of magnetic nanoparticles with an external magnetic field. The third member in equation (2) describes interaction of magnetic nanoparticles with anisotropic molecules of NLCs. Here the condition is accepted, that magnetic particles are distributed in regular intervals and between them exists only magnetodipole interaction, and also in system there is no aggregation and segregation of magnetic nanoparticles.

Orientation ordering of NLCs with impurity magnetic nanoparticles is characterized by the high magnetic sensitivity that exhibits in the magnetic field-induced rotation of the molecular anisotropy axis at magnetic fields exceeding some threshold values. The analysis of the equation (2) show that the basic mechanism of the magnetic field-induced orientation ordering of the impurity NLCs consists in the indirect effect of magnetic field on anisotropy molecules via magnetic nanoparticles. Even at low concentrations of ferromagnetic nanoparticles in the NLCs about 0.1% and not high magnetic field, the contribution of corresponding deformation forces to the ordering energy is much more than in the case of the pure NLCs ($|\chi| \leq 10^{-5} |M_s(\vec{e}\cdot\vec{H})| >> |\chi\chi_a(\vec{n}\cdot\vec{H})^2|$).

Our theoretical estimates [6, 7] showed that for the case of rigid coupling between ferromagnetic nanoparticles and nematic crystal molecules, the threshold magnetic field, which can cause the orientation ordering due to magneto-induced deformation, is two orders of magnitude lower than the threshold magnetic field, which can cause similar ordering due to the diamagnetic effect.

The magnitude of the critical magnetic field, which leads to the magnetically induced deformation ordering of the impurity NLCs is proportional to the coefficients of elasticity and proportional to the force of adhesion of magnetic nanoparticles to anisotropy molecules. The critical magnetic field is also inversely proportional to the concentration and magnetic moment of magnetic nanoparticles.

The practical use of the magnetic impurity NLCs in systems for measuring the inhomogeneous distribution of the magnetic field is based not on the effect of their ordering, but on measuring the rotating of the liquid crystal director under the action of such a magnetic field. The orientation of the liquid crystal causes it to become anisotropic, and the direction of its director coincides with the optical axis of such a uniaxially anisotropic crystal. When a linear polarized light passes through such an anisotropic uniaxial crystal, a phase difference $\delta = 2\pi/\lambda[n_e(\lambda) - n_0(\lambda)]d$ occurs between the extraordinary and ordinary polarized light. Where $n_e(\lambda)$ and $n_0(\lambda)$ is extraordinary refractive index and ordinary index of refraction, $k=2\pi/\lambda$ is the wave vector of light.

Linearly polarized light is elliptically polarized after passing through such an optically anisotropic crystal. The amount of eccentricity of ellipse of polarization depends on the phase difference between extraordinary and extraordinary polarized light, as well on the angle between the director of NLC and the plane of polarization of light on the entrance surface of the liquid crystal. The intensity I of such elliptically polarized light after passing through the analyzer depends not only on the optical difference between the normally and unusually polarized light beams, but also depends on the orientation of the polarizer and the analyzer relative to the direction of the liquid crystal director [9]

$$I = I_0\left[\cos^2(\alpha-\beta)-\sin 2\alpha\cdot\sin\beta\cdot\sin^2(\delta/2)\right] \quad (3)$$

Where I_0 is intensity light at the entrance to the liquid crystal, α is the angle between the director and the polarizer, and β is angle between the director and the analyzer.

Based on equation (2), we can show that under the action of a magnetic field *H*, the director of an oriented liquid crystal with nanoparticles will rotate in the direction of the acting magnetic field on some angle $\varphi(H)$. As already noted, the value of angle $\varphi(H)$ depend on value of magnetic field on coefficients of elasticity of liquid crystal, on force of coupling of magnetic nanoparticles with molecules of the liquid crystal, on concentration and the magnetic moment of magnetic nanoparticles.

The new intensity $I(H)$ of the polarized light after passing through the analyzer can be estimated as

$$I(H) = I_0\left[\cos^2(\alpha-\beta)-\sin 2(\alpha+\varphi)\cdot\sin(\beta+\varphi)\cdot\sin^2(\delta/2)\right] \quad (4)$$

From the results of light intensity measurements after the analyzer, it is possible to determine the magnitude of the angle and find the magnitude of the magnetic field that exerts on the NLC. It is clear that in the system of measuring the inhomogeneity of the magnetic field it is necessary to use a magneto-sensitive recording layer based on liquid crystals with magnetic nanoparticles, which is made in the form of a raster with mxl magnetically sensitive cells. The transverse size of the magnetically sensitive cells is determined by the technical requirements for the resolution of the magneto-sensitive layer. Technological developments today allow to produce a raster layer of liquid crystals of large area (more than 100 mm) with a minimum cell size of up to several tens of microns.

II. EXPERIMENT AND RESULTS

In our studies, we used oriented and undirected samples of pure NLCs (without magnetic nanoparticles) and impure NLCs (with magnetic nanoparticles). These samples in the form of a plane-parallel layer with 250-300 μ thick were obtained by applying the pure NLCs and the impure NLCs on pre-prepared two glass or quartz plates. For planar orientation of the NLCs on the surface of transparent glass (or fused quartz) substrates was applied a layer of polyamide varnish or polyvinyl alcohol with a 1 μm thickness. The directional molecular orientation of the NLC samples obtaining by a method of the directional rubbing surfaces/

Magnetic Fe_3O_4 nanoparticles were added into the NLC solution. The concentration of such nanoparticles was within from 2% to 7% by the solution weight. The magnetic nanoparticles were distributed by vibration evenly in the NLC solution. The quality of the NLC in the studied samples and the uniformity of the magnetic nanoparticle distribution were controlled using a polarizing microscope and an atomic force microscope with a magnetic measuring head.

The size of the samples was 18×18 mm and 3×3 mm. Larger samples were used for spectral studies. Smaller samples were used for studies of the sensitivity and dynamic characteristics of the magneto-sensitive layer of the impurity NLC. On two opposite surfaces of epy small sample were placed electrodes.

The scheme of measurements of sensitivity and dynamic characteristics of the magnetosensitive layer of the impurity NLCs is presented in figure 1. In this measurement scheme the semiconductor laser 1 with wavelength λ=*650 nm* emitted light pulses with duration of $\tau=10^{-4}$ *s* and with repetition frequency *1 kHz*. These pulses passed through the polarizer 2, the liquid crystal layer 3 and the polarizing prism of Senarmon 4 and were recorded using two photodetectors 5, two amplifiers 6, two-channel analog-to-digital converter 7 and the personal computer 8. The magnetic field was directed in the plane of the test samples, and it was generated by two pairs of Helmholtz coils 9, which allowed the simultaneous supply of alternating and constant magnetic field or alternating magnetic fields of different frequencies. This research scheme allows to measure the polarization twisting of linearly polarized light with a measurement accuracy of up to 0.01 degrees.

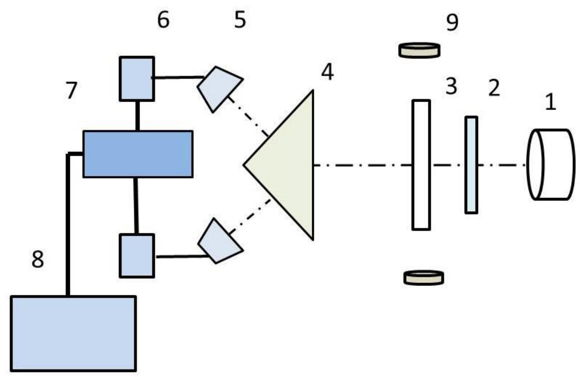

Fig. 1. The scheme of measurements of characteristics of the magnetically sensitive layer with magnetic nanoparticles: 1 - semiconductor laser, 2 - polarizer, 3 - liquid-crystal sample, 4 - polarization prism Senarmon, 5 - two photodetectors, 6 - two amplifiers, 7 - two-channel analog-digital converter, 8 - personal computer, 9 - Hemholtz coils

At spectral measurements of transmission of samples of the NLC the light source was a special lamp, the radiation of which was modulated by a mechanical modulator. In such measurements, the analyzer was a Glan prism, and the intensity of the light beam after the analyzer was recorded by the method of synchronous detection using an automated spectrophotometer. The magnetic field was created by a powerful iron-core electromagnet in the center of which a hole was drilled for optical measurements. The results of our first measurements showed that the effect of the magnetic field on the NLCs depends not only on the presence of ferromagnetic nanoparticles but also strongly depends on the state of the crystal orientation (Figure 2). This figure presents the value of the angle of effective polarization twisting of linearly polarized light after passing through the impurity NLC with magnetic nanoparticles Fe_3O_4 and through the analyzer, which is oriented at the angle of 45^0 relative to the polarizer. We measured the change in light signal after the sample and the analyzer without the magnetic field and in the magnetic field. We measured the change in light signal after the sample and the analyzer without the magnetic field and in the magnetic field. To increase the accuracy of the measurement was performed three times for each wavelength: without a field and in a field of the same intensity but different (opposite) direction. The effective value of the angle of rotation of the plane of polarization of the probing light under the action of a magnetic field was determined by the formula $\phi = ar\cos(\sqrt{I_2/2I_1}) - 45^0$, where I_1 is the intensity of light passing through polarizers without a magnetic field, I_2 is the intensity of light in the presence of a magnetic field

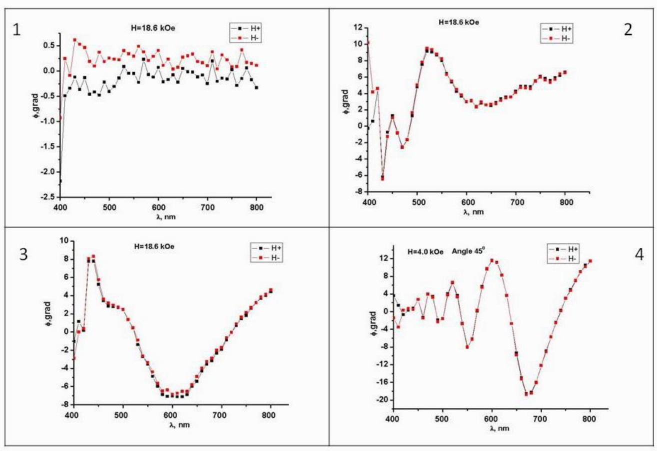

Fig.2. The effective value of the angle of rotation of the plane of polarization of linearly polarized light after passing through the nematic liquid crystal: 1 –

nonoriented liquid crystal without magnetic nanoparticles; 2 - nonoriented liquid crystal with magnetic nanoparticles Fe_2O_3; 3 -oriented liquid crystal without magnetic nanoparticles; 4 - oriented liquid crystal with magnetic nanoparticles Fe_2O_3

In the non-oriented sample without nanoparticles, the strong magnetic field $H \approx 2$ *kOe* directed perpendicular to the plane of the NLC sample does not cause change in the polarization of linearly polarized light passing through the NLC (Fig. 2-1). In the non-oriented sample with magnetic nanoparticles Fe_3O_4 (Fig. 2-2) under the action of such a field is the polarization twisting of linearly polarized light by the angle ϕ, the value of which is the same for the opposite orientation of the field vector. The magnitude of the angle ϕ depends on the wavelength of light and in the region of the maximum reaches almost 10^0.

In the oriented sample without nanoparticles (Fig. 2-3), the magnetic field $H \approx 2$ *kOe*, which is directed perpendicular to the plane of the liquid crystal sample and, accordingly, perpendicular to the direction of its director, causes the polarization twisting of linearly polarized light by some angle ϕ. The magnitude of this angle is also the same for opposite directions of the magnetic field and it changes with the wavelength of light.

In the oriented sample with Fe_3O_4 magnetic nanoparticles (Fig. 2-4), even a much weaker magnetic field, which is directed parallel to the plane of the liquid crystal sample and perpendicular to the direction of its director, causes a more significant rotation of the polarization plane of linearly polarized light. The value of this angle reaches almost 20^0 and its value has several maxima at different wavelengths of light.

Spectral studies have also shown that in the impurity NLCs the rotation of the NLC director is observed at a much lower magnetic field and takes place in a much shorter period of time than in undirected nematic liquid crystals with magnetic nanoparticles. The similar conclusion can be drawn from the results of experimental studies conducted by other authors [10, 11].

Since the rate of reorientation of the liquid crystal director in a magnetic field and the sensitivity of this process to the active magnetic field are very important characteristics when using the impurity NLCs with magnetic nanoparticles as a magnetically sensitive layer, we conducted additional research.

We investigated the dependence of the rotation angle of the NLCs on the magnetic field. During the measurements, the transmission plane of the polarizer was at an angle of $\alpha = 45^0$ with respect to the direction of the NLC director, and the analyzer (Senarmon prism) was set so that the transmission plane of one channel was parallel and the transmission plane of the second channel was perpendicular to the polarization transmission plane. The magnetic field acted in the plane of the sample and its direction was at an angle of 45^0 with respect to the direction of the director of the oriented liquid crystal. The magnitude of the signal for the first and second photodetectors is determined in the absence of a magnetic field by the following formulas

$$I_1 = A_1 I_0 \left[1 - \sqrt{2}/2 \cdot \sin^2(\delta/2) \right]$$
$$I_2 = A_2 I_0 \left[\sqrt{2}/2 \sin^2(\delta/2) \right] \quad (5)$$

where A_i is coefficient.

In expression (5) I_1 and I_2 are the values of the signal value from the photodetector for the case of parallel and perpendicular orientation of the transmission plane of the Senarmon prism relative to the transmission plane of the linear polarizer. From equation (5) we can find the phase difference between extraordinary and ordinary polarized light, which passed through an oriented liquid crystal with magnetic nanoparticles in the absence of a magnetic field.

The value of photodetector signals at magnetic field action can be defined as

$$I_1(H) = A_1 I_0 \left[1 - \sqrt{2}/2 \cos 2\varphi \cdot [(\cos\varphi + \sin\varphi) \cdot \sin^2(\delta/2)\right]$$
$$I_2(H) = A_2 I_0 \left[\sqrt{2}/2 \cos 2\varphi \cdot (\cos\varphi + \sin\varphi) \cdot (\delta/2)\right] \tag{6.1}$$

$$I_1(H) = A_1 I_0 \left[1 - \sqrt{2}/2 \cdot \cos 2\varphi \cdot (\cos\varphi - \sin\varphi) \cdot \sin^2(\delta/2)\right]$$
$$I_2(H) = A_2 I_0 [\sqrt{2}/2 \cdot \cos 2\varphi (\cos\varphi - \sin\varphi) \cdot \sin^2(\delta/2)] \tag{6.2}$$

If we put the coefficients of proportionality equal ($A_1 = A_2$), then we obtain simple expressions for calculating the value of the angle φ

$$[I_1(H) - I_1(0)]/I_2(0) = 1 - \cos 2\varphi \cdot (\cos\varphi + \sin\varphi),$$
$$I_1(H)/I_2(0) = \cos 2\varphi \cdot (\cos\varphi + \sin\varphi) \tag{7.1}$$

$$[I_1(H) - I_1(0)]/I_2(0) = 1 - \cos 2\varphi \cdot (\cos\varphi - \sin\varphi),$$
$$I_1(H)/I_2(0) = \cos 2\varphi \cdot (\cos\varphi - \sin\varphi) \tag{7.2}$$

Expressions (6.1) and (7.1) give the values of the photodetector signals for the case when due to rotation director of the NLC under the action of a magnetic field on the angle φ there is an increase in the angle α. This rotation of the NLC director with magnetic nanoparticles occurs when the magnetic field is directed perpendicular to the transmission plane of the linear polarizer. Expressions (6.2) and (7.2) give the values of the photodetector signals for the opposite case, when the rotation of the liquid crystal director by an angle leads to a decrease in the angle. This rotation of the NLC director occurs when the magnetic field is directed parallel to the transmission plane of the linear polarizer.

Out of results of the measurement of angle φ (***H***) of rotation of the director we can determine the magnitude of the magnetic field strength ***H*** which leads to rotation of the director in the oriented impurity NLC with magnetic nanoparticles. It is clear that for practical use it is necessary to carry out a preliminary calibration of the measurement system and on the basis of comparison of reference data and measurement data to determine the magnitude of the magnetic field strength.

The results of our measurements showed that in oriented NLCss with magnetic nanoparticles, the magnitude of the rotation angle of the director φ(H) depends nonlinearly on the magnetic field strength H and the concentration of magnetic nanoparticles (Figure 3). This figure shows the results of the calculation according to formulas (5) and (6) of the angle of rotation of the director in oriented samples with a size of *18x18 mm* with different concentrations of magnetic nanoparticles. Samples of liquid nematic crystals were oriented due to interaction with the substrate. The reference magnetic bias field and the measuring pulsed magnetic field were applied to the sample. The reference magnetic field had a fixed frequency of *1 Hz* and different amplitude H_0. The measuring magnetic field H_i was generated by a sequence of electric pulses of the same polarity, the duration of which was 5 milliseconds, and the interval between pulses - 10 milliseconds.

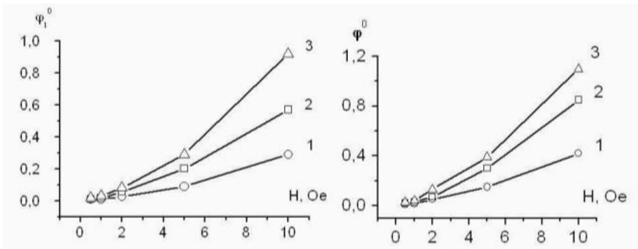

Fig. 3 Dependence of the angle of rotation of the director of oriented liquid nematic crystals with magnetic nanoparticles on the intensity of the measuring H_i magnetic field at different concentrations magnetic nanoparticles (I –N=3%, II – N=5%) and at different values of reference magnetig field H_0: 1–H_0=1 Oe, 2–H_0=10 Oe, 3–H_0=20 Oe.

The research results show that at the same magnetic field the value of the rotation angle of the director is larger in samples of NLCs with a higher concentration of magnetic nanoparticles. In addition, the magnitude of angle of rotation φ(H) of the director in our samples increases nonlinearly with increasing applied magnetic field strength. Thus, the nonlinear dependence φ(H) allows to implement for the magnetically sensitive layer on the basis of nematic liquid crystals with magnetic nanoparticles the mode of parametric amplification of the input signal of the measured magnetic field. To do this, an additional magnetic field with the specified parameters must be applied to the magnetically sensitive cell of the liquid crystal.

We tried to implement this mode in experiments when working with small *3×3 mm* samples. Investigations of the influence of the magnetic field on the reorientation of the director in the *3×3 mm* sample of the nematic crystal with magnetic nanoparticles were performed according to the scheme shown in Fig.1. The orientation of the director in samples of *3×3 mm* was carried out due to the applied electric field. Pulses of the electric field of the same polarity were applied to electrodes that were applied to opposite face of the sample. The duration of each pulse was $\tau_i=10^{-3}$ *s,* and the interval between pulses $\tau_t= 5\times10^{-3}$ *s*. Under the action of such electric pulses in our *3×3 mm* sample, almost 100% orientation of the nematic crystal director with magnetic nanoparticles was observed.

The measuring pulsed magnetic field H_i of one polarity and an reference magnetic bias field H_0 with a frequency of *5 Hz* acted on the sample. The pulse repetition frequency of the measuring field was 100 Hz, and the duration of one pulse was $\tau_i=3\times10^{-3}$ *s*.

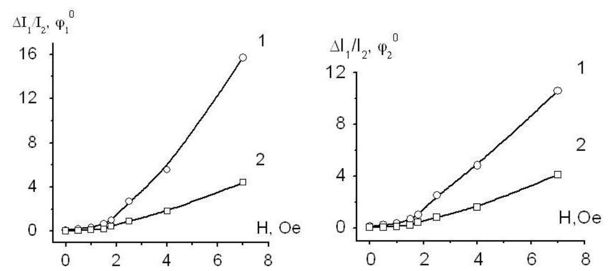

Fig. 4. The difference of photoelectric signals $\Delta I_i(H)/I_2(0)$ and the value of the angle φ(H) induced by the measuring pulsed magnetic field H_i: 4–I – the value of the angle φ(H) was calculated by expression (7.1), 4 – II – the value of the angle φ(H) was calculated by expression (7.2), the amplitude of magnetic bias field is 2 Oe.

In the first case, the magnetic field was directed in the plane of the sample at the angle *45⁰* to the direction of director orientation of the NLC, but parallel to the plane of transmission of the polarizer. In the second case, the direction of the magnetic field was also in the plane of the sample at the angle *45⁰* to the direction of the NLC director but the magnetic field was perpendicular to the direction of the polarizer transmission. The results of measurements and calculations of the angle φ are presented for the first case in figure 4–I and for the second case in figure 4–II. The value of the angle φ for figure 4–I was calculated by expression (7.1), and for figure 4–II was calculated by expression (7.2), and the data for absolute values are given. It occurs because the size of a photoelectric signal in the channel *1* decreases under the influence of a magnetic field which is directed perpendicularly to transmission plane of linear polarizer.

The results of our experimental studies show that the purity NLCs can be used in recording systems of inhomogeneous low-frequency magnetic field. It is clear that to create an effective magnetically sensitive layer based on the purity NLCs, it is necessary to carry out technological and design developments to optimize the composition and structure of the material, as well as the optical system of reading and processing data.

In this paper, we want to propose one of the possible schemes for constructing a system for detection of inhomogeneous magnetic field based on liquid crystals with magnetic nanoparticles (Fig. 5).

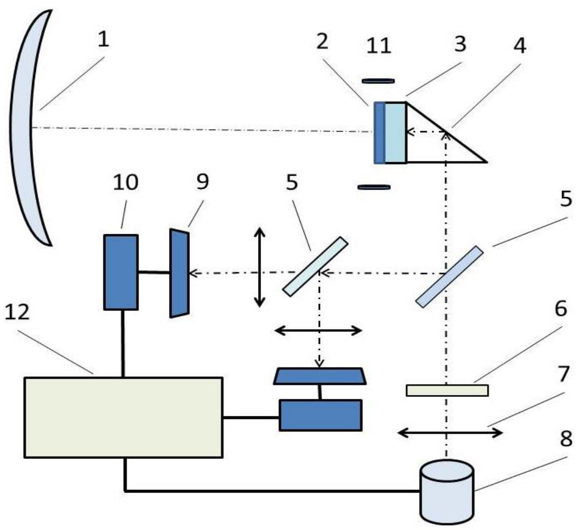

Fig. 5. Scheme of the system for detection of inhomogeneous magnetic field. 1 - spherical mirror, 2 - nonmagnetic reflective layer, 3 - magneto-sensitive liquid crystal sensor, 4 - totally reflecting prism, 5 - two interference polarization mirrors, 6 - polarizer, 7 - lens system, 8 - laser, 9 - two photodetectors matrix type, 10 - two blocks of amplification and signal conversion, 11 - magnetic field source, 12 - control and data processing unit.

The peculiarity of this system is that the magnetically sensitive sensor is made in the form of a raster layer, which consists of *m*x*m* cells filled with a non-matrix liquid crystal with magnetic nanoparticles. An electric field is applied to each cell of the raster layer to orient the NLC. One flat surface of the raster layer is connected through optical contact with the prism of full internal reflection, and on the opposite surface is applied a reflective optical coating of non-magnetic material. The raster layer is placed in the focal plane of the spherical mirror, the surface of which is coated with a reflective coating of magnetic material with a high value of magnetic susceptibility. In addition, two multilayer interference polarization mirrors are introduced into the optical reading system. These mirrors transmit *p*–polarized radiation and reflect *s*–polarized laser radiation.

The system for detection of inhomogeneous magnetic field described above allows to detect an unknown object that makes certain changes in the uniform distribution of the magnetic field in the plane of the raster magneto-sensitive layer, and to identify an unknown object by comparing its image parameters with image parameters of etalon objects.

We hope that the results of this work allow us to talk about a good prospect for the practical use of the impurity NLCs with magnetic nanoparticles to register the magnetic field. When developing prototypes of the NLC magnetic layer, it should be borne in mind that to increase the sensitivity to the magnetic field of the NLCs with magnetic nanopaticals and the rate of reorientation of their director under the action of a magnetic field, it is necessary to use oriented liquid crystals. This approach will also increase the sensitivity of the magneto-sensitive layer and allows you to implement the mode of parametric amplification of read signals. In addition, the reorientation time of the NLC director will decrease as the geometric size of the recording cell decreases. Raise the technical characteristics of the magneto-sensitive layer based on liquid crystals with magnetic nanopaticals is possible by optimizing the shape, magnetic characteristics and concentration of magnetic nanopaticals. To increase the stability and lifetime of the magnetic sensitive layer based on the impurity NLCs with magnetic nanopaticals is possible by coating magnetic nanoparticles with surface-active substance, as well as by using alternating low-frequency magnetic field as an additional magnetizing magnetic field.

All this shows that for the practical use of NLCs with magnetic nanoparticles it is necessary to carry out multilateral technological and design work. However, the possibility of manufacturing a NLC magneto-sensitive layer in the form of a raster with a large area and a large number of cells, as well as the high sensitivity of polarization reading methods indicate a good prospect for the practical application of such developments.

III. REFERENCES

[1]. Henry W. Ott. Noise Reduction Techniques in Electronic Systems. New York, NY: 1988. 426 p.

[2]. Patent EP2927678A4, Magnetic measuring system for a flaw detector having longitudinal magnetization. A.D. Miroshnik, S.F. Gurin, A.A. Krasnov, M.V. Lapin 01, 2014;

[3]. United States Patent US20080150525A1, Method and apparatus to improve spectral resolution in an inhomogeneous magnetic field, Yi-Qiao Song, 2008;

[4]. United States Patent USOO6967478B2, Details specially adapted for scanning by moving the sensors, M. Wayman, D. Dickson, 2005;

[5]. US6774627B2, Leak magnetism detection sensor for magnetic flaw detection system, H. Yokota, Y. Tomura, H. Unzaki, S. Tsuruoka, 1970

[6]. United States Patent US 4433289, Primary Class: 324/215. A method for inspecting steel billets with a dry mixture of magnetic particles and a water soluble carrier solid, Mlotfijalkowski A., Borrows P., 1984;

[7]. United States Patent US 9,255,978 B2, Magnetic assembly and method for defining a magnetic field for an imaging volume, B. Gino Fallone, T. Tadic, B. Murra, 2016.

[8]. United States Patent US8362762B2 G01R33/032, Magnetic Field Measurement Device, Inventor: Ryuji Hokari, Date of Patent: Jan. 29, 2013.

[9]. Ditchburn R. W. Light Dover Publications Inc. New York, 2011, 736 p.

[10]. Almuatasim Alomari ; Maria Pour ; Robert G. LindquistMagnetic and Optical Study of Nematic Liquid Crystal E7 Mixed Fe3O4 Ferrofluid IEEE Transactions on Magnetics (Volume: 55 , Issue: 12 , Dec. 2019) DOI: 10.1109/TMAG.2019.2936806.

[11]. Emil Petrescu, Cristina Cirtoaje, Cristina Stan. Dynamic behavior of a nematic liquid crystal mixed with CoFe2O4 ferromagnetic nanoparticles in a magnetic field Beilstein J Nanotechnol. 2017; 8: 2467–2473.

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