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"Our conceptual universe is merely the simplest logical construct into which we can gather all known, perceived phenomena..."

Karl Pearson

THE FIRST RESULTS OF THE EXPERIMENT ON REGISTRATING LIGHT DRAGGING OBSERVED IN AN INTERFEROMETER WITH A ROTATING MEDIUM

Gladyshev V.O., Gladysheva T.M., Zubarev V.E.

Optical Electronical Department of N.E.Bauman Moscow State Technical University, 5 2-nd Baumanskaya st. 107005 Moscow, Russia

Natural Sciences Department of Egoryevsk Aviation Technical College, 2 Vladimirskaya st. Egoryevsk 140303 Moscow region, Russia, E-mail: vgladyshev@mail.ru

1. INTRODUCTION

Light dragging by a moving medium consists in dependence of the phase velocity of light in a moving medium upon velocity of the medium [1]. This phenomenon has fundamental nature in moving medium optics, and provides a classical example of the relativistic velocity composition law and is a basis for creating of moving medium electrodynamics.

When an electromagnetic wave is incident onto the moving medium with the tangential velocity break, the deflection of the refraction angle in a moving medium from the refraction angle in a static medium occurs. As a result of the deflection, light beam trajectories curve in a homogeneous medium with complex motion [2].

Experimental registration of these effects is new testing the relativity and existing understanding on light interactions with a moving medium in a general case.

The goal of this work is to develop an interference method for investigating the spatial effect of the light dragging in a rotating medium, to create an interferometer and also to detect a phase shift for beams propagated a rotating medium.

2. ESTIMATION OF THE EXPECTED SHIFT OF AN INTERFERENCE PATTERN

For achieving this goal it was designed and built the double-beam two-pass disk interferometer with inputting beams into the flat surface of an optical disk (figure 1).

Compensating deference features of the scheme provided high protection against mechanical disturbances.

The interferometer is tuned to the interference fringes of equal thickness and determined the shift of the light interference pattern using the time signal from photodetector, when the optical disk (OD) rotates. The interference pattern (IP) shifts in the plane of analysis of the IP in the direction, which depends on the rotation direction. In this case the IP shift can be determined on the time of IP passage across a photodetector for the forward and reverse directions of rotation.

This method of picking out a signal is more preferred in comparison with the method of measuring the variations of IP intensity, because of the time of IP motion is measured with the equipment, which has higher relative resolution and stability of parameters.

For estimating the expected IP shift due to the longitudinal light dragging, it can be used the solution of the dispersion equation, by neglecting the tangential component of the velocity of the medium ($\beta_{2x} = 0$). The electromagnetic wave vector projection on the axis OZ in the second medium is equal to [3]

$$k_{2z} = \frac{\omega_0}{c} \frac{-\kappa_2 \gamma_2^2 \beta_{2z} \pm \sqrt{1 + \kappa_2 \gamma_2^2 \left(1 - \beta_{2z}^2\right)}}{1 - \kappa_2 \gamma_2^2 \beta_{2z}^2}, \qquad (1)$$

where $\kappa_2 = \varepsilon_2 \mu_2 - 1$, $\gamma_2^{-2} = 1 - \beta_2^2$, $\beta_{2z} = \frac{u_{2z}}{c}$, ω_0 - electromagnetic wave frequency,

c - the phase light velocity in the vacuum, ε_2, μ_2 - the dielectric and magnetic permeabilities of the medium, u_{2z} - normal component of the medium velocity.

Considering $\beta_{2z} >> \beta_{2z}^2$, we obtain the expression for the phase light velocity in a rotating medium

$$c' = \frac{\omega_0}{k_{2z}} = \frac{c}{n_2} \pm \mathrm{pr}_{\vec{k}} \vec{u}_2 \left(1 - \frac{1}{n_2^2}\right), \tag{2}$$

where the projection of the medium velocity vector onto the wave vector:

$$\mathrm{pr}_{\vec{k}} \vec{u}_2 = u_{2z} \cos\vartheta_2 + u_{2x} \sin\vartheta_2 . \tag{3}$$

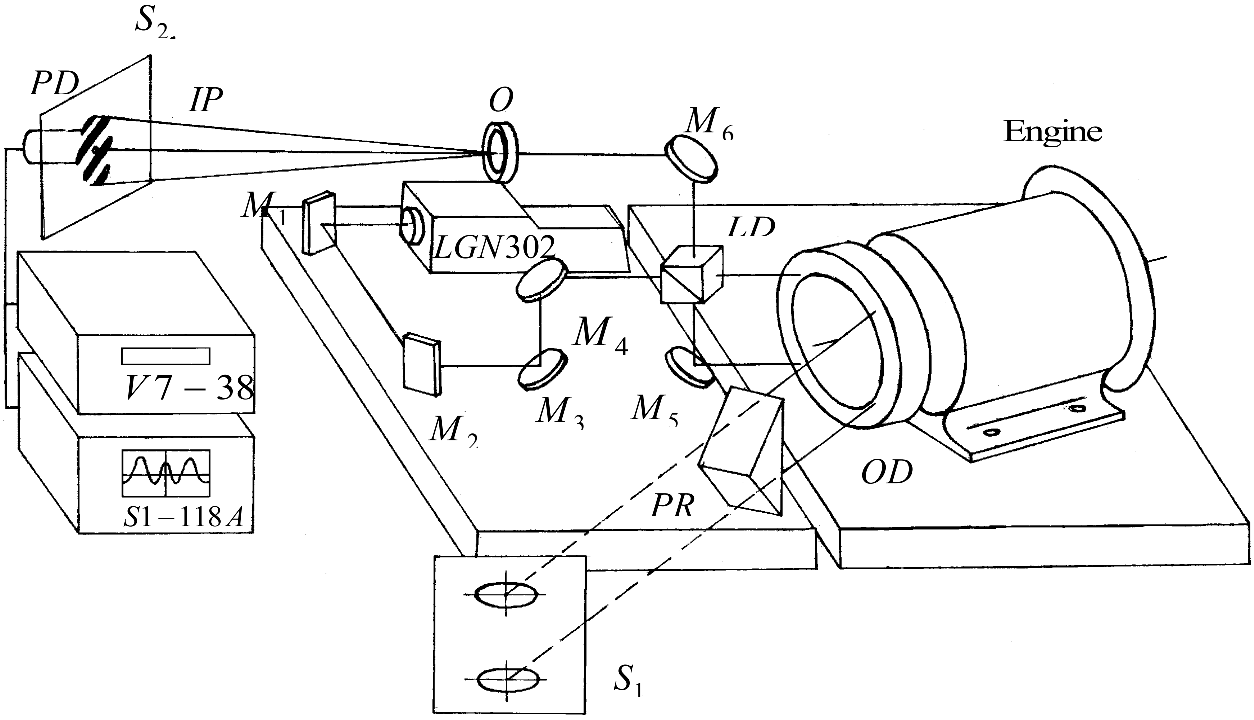

Fig.1. The scheme of the interferometer with a rotating optical disk

When beams pass through the rotating OD one time, the IP shift is equal to

$$\Delta_0 = \frac{c}{\lambda}(t_2 - t_1), \tag{4}$$

$$t_1 = \frac{d}{\cos\vartheta_2 \left(\frac{c}{n_2} + \left(1 - \frac{1}{n_2^2}\right)\omega r \sin\vartheta_2\right)}, \quad t_2 = \frac{n_2 d}{c \cos\vartheta_2}, \tag{5}$$

where t_1, t_2 - the times of passing through the rotating and static OD, respectively, ω and d -the angular velocity and the OD thickness, respectively.

After substituting t_1, t_2 into (4), we obtain in the limit $\omega r << c$:

$$\Delta_0 = \frac{\omega r d (n_2^2 - 1)}{\lambda c} tg\,\vartheta_2 . \tag{5}$$

Let notice that from figure 2 it follows

$$d \mathrm{tg}\vartheta_2 = \sqrt{R^2 - r^2} = l/2 . \tag{6}$$

Here R -the OD radius, l - the projection of beam path in OD onto the flat surface of the disk.

We may notice that the determined value of IP shift Δ should be equal to $32\Delta_0$. First, the disk edge surfaces are mirror coated, increases in the optical path twice. After reflecting from a prismatic reflector (PR) the beams repeatedly pass through OD, which also increases the resulting IP shift by a factor 2. The second beam passes through OD in the reverse direction and accumulates difference of optical pass with opposite sign, which increases the resulting IP shift by a factor 2 too. The change of the direction of rotation leads to the change of the direction of the IP shift, which allows increase the resulting IP shift by a factor 2. Moreover, measurements can be carried out for two adjustments of the interferometer, for which the same direction of rotation is matched by two different directions of IP shift. Carrying out the experiments for two deferent adjustments allows increase the resulting IP shift by a factor 2 again.

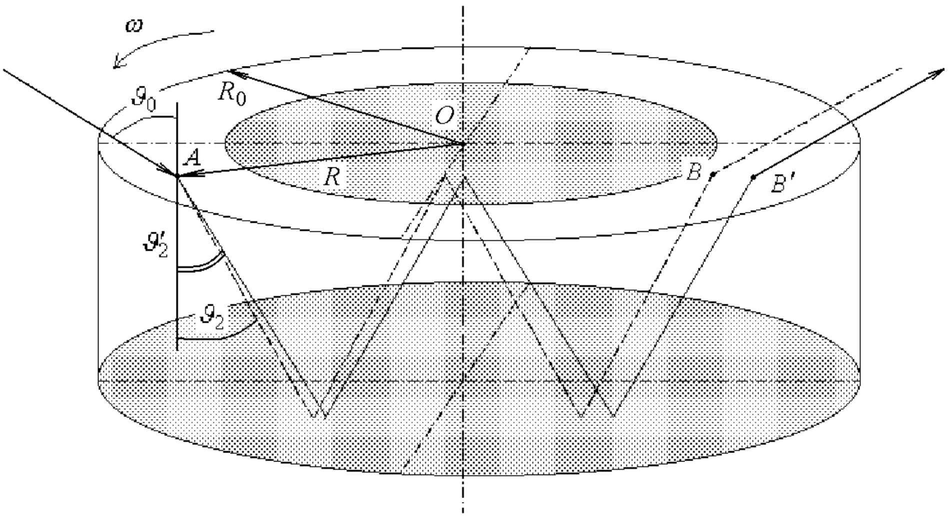

Fig. 2. The scheme of beam propagation in a rotating medium. As the refractive angle depends on the rotation velocity of the medium, the point of a beam exit out the optical disk moves from the point B to the point B'

As a result of this we can write, using (5) and (6)

$$\Delta = \frac{16 l u_{2n}(n_2^2 - 1)}{\lambda c}, \tag{7}$$

where $u_{2n} = \omega r$ - the linear medium velocity along the light beam trajectory.

In reality, the IP shift can be increased still further due to the refraction angle differs from the one, calculated by Snell's law, ϑ_2.

The solution of the dispersion equation, supposing $\beta_{2x} = 0$ and $\beta_{2z} >> \beta_{2z}^2$:

$$k_{2z} = \frac{\omega_0}{c}\left(-\kappa_2\beta_{2z} + \sqrt{\cos^2\vartheta_0 + \kappa_2}\right). \tag{8}$$

Then the expressions $tg\vartheta_2' = k_{2x} / k_{2z}$, $k_{2x} = \frac{\omega_0}{c}\sin\vartheta_0$ can determine the refraction angle in a moving medium

$$tg\vartheta_2' = \frac{\sin\vartheta_0}{-\kappa_2\beta_{2z} + \sqrt{\cos^2\vartheta_0 + \kappa_2}}. \tag{9}$$

Increasing the optical path length in OD is equal to the difference between the equivalent optical path l_e in a rotation medium and the one l_{0e} in a static medium:

$$\Delta\widetilde{l}_e = l_e - l_{0e} = 4dn_2\left(\frac{1}{\cos\vartheta_2'} - \frac{1}{\cos\vartheta_2}\right). \tag{10}$$

If OD is stationary, a beam passes the path in air. Increasing the optical path length is equal to

$$\Delta l_e = \Delta\widetilde{l}_e\left(1 - \frac{1}{n_2}\right). \tag{11}$$

This value characterizes the additional pass difference of the beam, have been passing the OD one time in one direction, because of deflection from Snell's law.

The resulting value of the additional shift due to this effect with account of all passes of two beams for all directions and adjustments in our experiment is equal to

$$\Delta_S = 16\frac{\Delta l_e}{\lambda}. \tag{12}$$

Also, we can estimate the value of the additional IP shift as a result of the curvature of a beam motion trajectory in a rotating medium. However for our scheme the both opposite beams have the curved trajectories, so the resulting value of the IP shift will tend to zero.

The summary IP shift, which is a result of the light dragging effect and the deviation from Snell's law, is

$$\Delta_\Sigma = \Delta + \Delta_S. \tag{13}$$

On a basis of the formulae (7), (9)-(13) it was calculated the expected IP shift with the interferometer parameters, which was used in our experiment: $l = 0{,}0892$ m, $r = 0{,}024$ m, $\omega \cong 25$ Hz, $\lambda = 0{,}632991$ μm, $n_2 = 1{,}48$, $\vartheta_0 = 62^\circ$:

$$\Delta = 0{,}0054 \text{ bandwidth}, \tag{14}$$

$$\Delta_S = 0{,}0013 \text{ bandwidth}, \tag{15}$$

$$\Delta_\Sigma = 0{,}0067 \text{ bandwidth}. \tag{16}$$

Therefore, in the experiment it should be measured the IP shift value is equal to $\Delta_\Sigma = 0{,}0067$ bandwidth.

3. REGISTRATION OF SPATIAL EFFECT OF LIGHT DRAGGING IN A ROTATING MEDIUM

To decrease the influence of vibrations, the optical system and the engine (E) with OD was placed on different platforms and tables (fig.1).

The signal from a photodetector (PD) came through a resistor system into oscillograph C1-118A. An optical disk was rotated by an engine for the modes of the right and left rotation. For these modes the digital camera Kodak DC240 with high resolution and a recording element recorded the oscillogramms (25 tests for each combination of rotation direction and an adjustment) and furthermore its was processed and analyzed with a personal computer.

In the experiment the gas-atomic stabilised laser LGN-302, operating in continuous mode, was as a light source.

An optical disk was an standard plate diameter of 120 mm and a thickness of 30 mm and was made of LK5 grade glass. Whole one edge surface of a disk and part of another edge surface of a disk with a diameter of 80 mm were coated to provide for the reflection coefficient $\rho = 0{,}9$.

After adjusting the OD, the spots of beams moved in ellipses on a screen S_1, when we slowly rotated the OD. Ellipticity of the curves is explained with the photoelastic effect.

In the experiment we used the achronous three-phase engine with rotating velocity 1400 rpm. Deviation of rotation period was within 1%.

The photodiode PD256 was as a photodetector in the plate of a screen S_2.

After adjusting the optical system, checking stability of an engine operating, achieving a stable IP, experiment was carried out.

When we used the first adjustment and the counterclockwise direction of engine rotation, interference fringes inclined to the right and were reset to the original position. When the engine was slowly rotated, it was observed that three bands passed across the photodetector aperture in the forward and reverse directions. The photodetector was arranged so that it was between minimum and maximum of intensity of a band in the stop position, in which directions of band motions altered (Fig. 3).

The main scale for the experiment was 1 ms per a graduation in order to the points 12 – 16 was accommodated in the oscillograph screen.

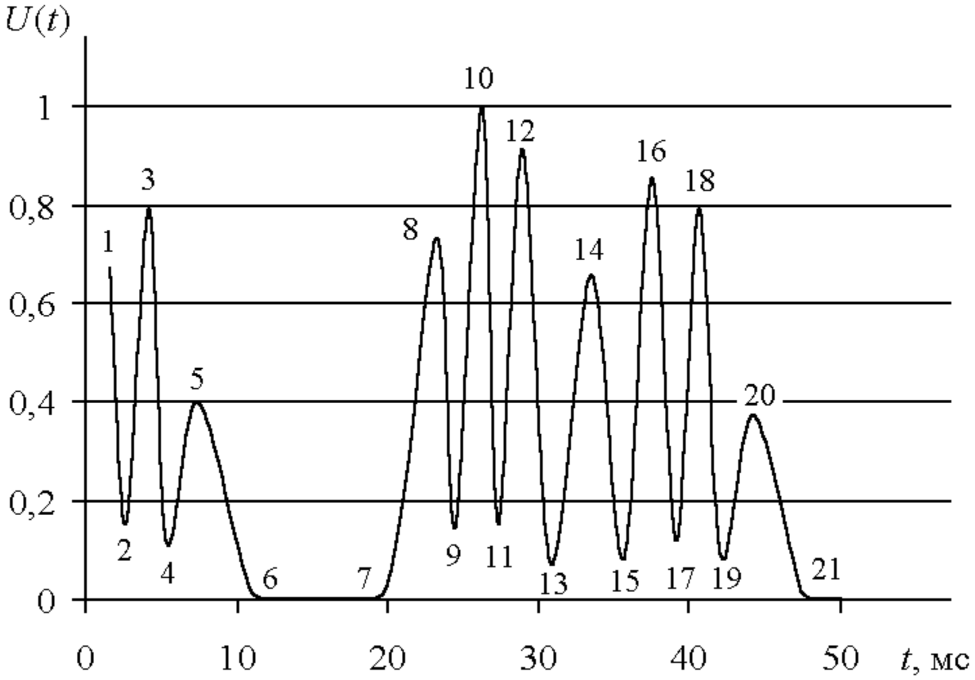

Fig.3. The dependence of the relative voltage on photodetector on the time for the second adjustment and first direction of rotation

The readings t_{kj}, where k -the number of a point, $j = \overline{1,\ 25}$ - the number of an oscillogramm, was taken from oscillogramms. Thereupon the values were calculated, using

$$\delta t_j = t_{15j} - t_{13j}, \tag{17}$$

$$\Delta t_j = t_{13j} - t_{12j} + t_{16j} - t_{15j}, \tag{18}$$

where δt_j corresponds to the time distance values between the IP stop point and the nearest interference band and Δt_j correspond to the time width of the interference band.

After this, we processed the oscillogramms, using the clockwise direction of engine rotation, in the same way.

The next adjustment was archived with inclining interference fringes to the left. Two direction of engine rotation was used also for the second adjustment.

In the experiment we detected time coordinates of the t_k points, when IP moved, so it is necessary to convert them to the spatial ones.

4. PROCESSING THE EXPERIMENTAL DATA

The relation Δt and δt determines the relative position of an interference fringe in the part of time bandwidth.

As it was notice, beams in a screen moved in ellipses. The ellipse length is determined as

$$L = a\int_0^{\varphi}\sqrt{1-\sin^2\alpha\,\sin\varphi d\varphi}\,, \tag{19}$$

$\sin^2\alpha = 1 - b^2/a^2$, a, b - the major and minor ellipse half-axis, φ - the parameter.

We can change the values Δt and δt for the ellipse arc lengths ΔL и δL, expressed in radians, respectively:

$$\delta L = \pi\frac{\delta t}{T}, \quad \Delta L_{\Sigma} = \delta L + \Delta L/2 = \pi\frac{\delta t + \Delta t}{T}, \tag{20}$$

where

$$\delta L = a\int_0^{\varphi_{15}}\sqrt{1-\sin^2\alpha\,\sin\varphi d\varphi} = a\,E(\varphi_{15}\setminus\alpha)\,, \tag{21}$$

$$\Delta L_{\Sigma} = a\int_0^{\varphi_{16}}\sqrt{1-\sin^2\alpha\,\sin\varphi d\varphi} = a\,E(\varphi_{16}\setminus\alpha)\,, \tag{22}$$

T - the period of IP vibrations, $E(\varphi_{15}\setminus\alpha)$, $E(\varphi_{16}\setminus\alpha)$ - the elliptic integral of the second kind, φ_{15}, φ_{16} - the parameters to be respective to the points 15 and 16.

Inserting the values Δt and δt, which was measured in the experiment, into (21), (22), we can get ΔL and δL_{Σ}. It follows from (20)-(22) that $a = 1$ due to the values Δt and δt normalised to the period T.

For δL and $\delta L + \Delta L/2$, and relation b/a, taken from the experiment, we can determine φ_{15} and φ_{16}.

The spatial position of a band from the point 14 is equal to

$$\delta y = b(1-\cos\varphi_{15})\,. \tag{23}$$

The spatial bandwidth is equal to

$$\Delta y = 2b(1-\cos\varphi_{16} - \delta y)\,. \tag{24}$$

The relative position of a band from the point 14 is determined as

$$\Delta = \frac{\delta y}{\Delta y} = \frac{1-\cos\varphi_{15}}{2(\cos\varphi_{15}-\cos\varphi_{16})}\,. \tag{25}$$

For two rotating directions and two adjustments of interfering beams we can obtain the resulting measured value of IP shift:

$$\Delta_{\Sigma} = (\Delta_1 - \Delta_2) - (\Delta_3 - \Delta_4)\,. \tag{26}$$

Let notice that calculating the IP shift is carried in for the values, which are normalized to a rotation period and to interference band width. Thus the results of the calculation don’t depend on period vibrations and band width from one measurement to the other.

The average rotation period is $\overline{T} = 0{,}0396$ s that is relative to rotation frequency $\nu = 25{,}26$ Hz.

For the series of the experimental data Δ_i the confidence intervals was calculated with the confidence probability $p = 0{,}9$.

Then the resulting value of IP shift was equal to

$$\Delta_{\Sigma}^{Exp} = 0.0076 \pm 0.0030\,. \tag{27}$$

The theoretical magnitude $\Delta_\Sigma = 0.0067$ appears in the confidence interval (27), moreover the relative error for the average value $\Delta_\Sigma = 0.0076$ is about 13%.

5. CONCLUSION

So the results of theoretical calculations of the expected IP shift for the used parameters in the experiment are in reasonably good agreement with the experimental results of the IP shift.

It should be notice that the rotation velocity in the experiment was not high. But spatial light dragging effect had influence on the IP shift. Therefore, electromagnetic wave dragging by a moving medium should be taken into account for using non-relativistic velocities of medium, and the effect may have an impact on results of different measurement procedures.

In order to make the final conclusion that the experimental results are in agreement with predictions of the relativity it is necessary to increase the experiment accuracy. It may be achieved by using the more stable engine with higher frequency of rotation and more sophisticated system of transforming signal from a photodetector.

REFERENCES

[1] Fizeau D'H. *Sur les hypotesis relatives a l'ether lumineux, et sur une experience qui parait demonter que le mouvement des corps change la vitesse avec laquelle la lumiere se propage dans leur interieur*// Ann. de Chimie et de Phys. 1859. V.57. P.385.

[2] Gladyshev V.O. *Curvature of the trajectory traced out by a monochromatic plane electromagnetic wave in a medium with rotation* //JETP Lett. (1993). V.58 (8), -pp.569-572.

[3] Bolotovski' B.M., Stolyarov S.N. //Uspekhi Fiz. Nauk. 1988. V.156. N.1, p.153-176.