The first results of the 3-D experiment for investigating a dependence of spatial light dragging in a rotating medium on speed of rotation

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Invariance of electrodynamics equations relative to transformations of Lorentz or Mehler is based on non-invariant relations for partial infinitesimal differentials of space and time variables [1].

It was shown before, that correct description for experiments of moving media optics is possible on the basis of solutions for the dispersion equation and with account dispersion in moving optical elements of an interferometer [2], [3].

A numerical Michelson-Morley - type experiment, in which an interferometer moves relative to an arbitrary inertial frame (IF), gives zero result when the interferometer is rotated, even if dispersion is taken into account.

Hence non-invariant properties can be found in experiments of moving media optics when there is no any IF where all elements of an interferometer rest. This condition is present in the Fizeau's interferometer where light beams propagate in moving water. In the case, when the Fizeau-type interferometer moves relative to the taken IF, its turn leads to variation of interference fringe. The variation amplitude is proportional to velocity of interferometer motion. More over, the variation of interference fringes will be more in the one-passage scheme (fig.1) in comparison with the two-passage that.

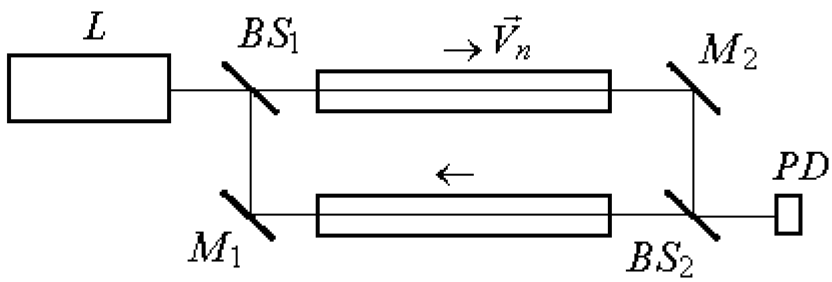

Fig.1. Fizeau-type interferometer with the one-passage scheme for laser beams.

For the resting Fizeau-type interferometer with the one-passage scheme the interference fringes shift is equal to [3]

$$\Delta_0 = \frac{2l}{\lambda}\frac{\beta_n(n^2-1)}{1-n^2\beta_n^2}, \tag{1}$$

where l - length of optical path for one beam in a moving medium, $\beta_n = V_n/c$, V_n - velocity of a moving medium in the IF of the interferometer, λ - length of light wave, n - index of refraction for a medium in the IF where the medium rests.

In the case when the interferometer moves, interference pattern (IP) shift is calculated with account: kinematical displacement of optical elements in the interferometer, length contraction, altering angles of reflection and refraction, Doppler's effect, the phenomenon of dispersion in material. By neglecting dispersion we can write

$$\Delta = \frac{\Delta_0}{1-\beta}, \tag{2}$$

where $\beta = V/c$, V - velocity of interferometer motion.

Difference between (2) and (1) determines magnitude of expected variation of fringes shift when the interferometer is turned relative to velocity vector of its motion

$$\delta_0 = \Delta - \Delta_0 \approx \beta\Delta_0 . \qquad (3)$$

For parameters of the Fizeau's experiment $l = 1{,}4875\,\text{m}$, $V_n = 7{,}059\,\text{m/s}$, $\lambda = 0{,}526\,\text{mkm}$, $n \approx 1{,}33$ we have got $\Delta_0 = 0{,}170$. Let us take as an example velocity of Sun system motion relative to our Galaxy $V = 250...300$ km/s, $\beta \approx 10^{-3}$. Then we will obtain the estimation $\delta_0 = 1{,}7 \times 10^{-4}$ for variation of fringes shift. Numerical calculations with accounting dispersion give lesser magnitude of shift $\delta = 0{,}29\delta_0 = 4{,}9 \times 10^{-5}$ [4]. The magnitude of fringes shift can be measured in modern experiments.

In the work the interferometer scheme (fig. 2) equivalent in the first approximation to the Fizeau-type interferometer with the one-passage scheme was suggested. In the interferometer a beam from laser L is divided by BS on two beams, which propagate in the rotating optical disk OD in two opposite directions after the mirrors M1 and M2. Because of OD rotation, one of the beams has positive phase shift, and another has negative that. After beams mix in BS, reflect from the mirror M3, and propagate in the optical system OS, they get onto the photodetector PD. Changing the direction of ОД rotation leads to altering the direction of fringes shift on PD.

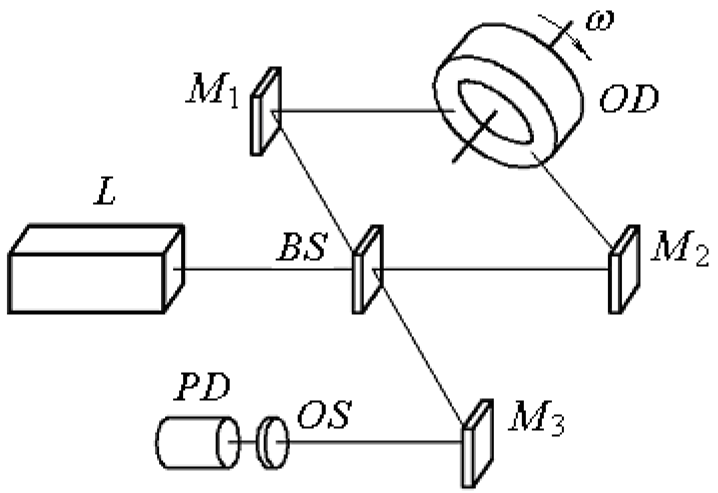

Fig.2. Two-beams one-passage interferometer with rotating OD.

In experiments the next parameters was used: rotation frequency $\nu = 200$ Hz, path length of one beam in a medium $l = 30$ mm, index of refraction of OD glass $n = 1{,}78$, OD thickness ОД $d = 20$ mm, incident angle of a beam on a flat surface of OD $\vartheta_0 = 53{,}5^\circ$. The expected magnitude of interference fringes shift due to the Fizeau's effect for the parameters is $\Delta_0' = 1{,}33 \times 10^{-2}$.

Hence theoretical analysis of the experiment shows that we need to take into account violation of the Snell's law due to availability of tangential break of velocity on the boundary between two media: air and glass.

We carried out experiments with an interferometer which scheme was close to the – Fizeau's-type two-passage interferometer [5], [6] before. In the experiments it was confirmed that additional interference fringes shift due to transverse Fizeau's effect can be about 25 % of total shift.

On account of transverse light dragging the refractive angle is calculated by using the formula

$$tg\vartheta_2' = \frac{\sin\vartheta_0}{\sqrt{n^2 - \sin^2\vartheta_0} - (n^2 - 1)\beta_n}, \tag{4}$$

In our experiment $\beta_n = 6{,}4 \times 10^{-8}$ defines the deviation angle ϑ_2' from $\vartheta_2 = arctg\frac{l}{3d}$ in about 2×10^{-6} degree.

Additional interference pattern shift is calculated with the expression

$$\Delta' = \frac{6d(n-1)}{\lambda}\left(\frac{1}{\cos\vartheta_2'} - \frac{1}{\cos\vartheta_2}\right) = 2{,}9 \times 10^{-3}. \tag{5}$$

Summary shift due to longitudinal and transverse Fizeau's effects is equal to $\Delta_\Sigma = \Delta_0' + \Delta' = 1{,}62 \times 10^{-2}$. Therefore, the expected value of fringes variation when the interferometer is turned relative velocity vector of the Sun in the Galaxy is $\delta_0 \approx \beta\Delta_\Sigma \approx 1{,}62 \times 10^{-5}$. By accounting influence of material dispersion the value can be reduced to $\delta = 0{,}29\delta_0 = 4{,}7 \times 10^{-6}$. The given magnitude of fringes shift is small, hence it may be measured. More over, there is a possibility to apply rotating disk with higher rotation frequency.

In the work the results of experiments on a new interferometer with a rotating optical disk (fig.2) are presented. The interferometer was constructed on two optical platforms with a passive vibroprotected system. A motor with optical disk was situated on the first platform and another optical part of the interferometer was based on the second that. Both platforms of the interferometer was mounted on a rotary platform.

In the experiments the stabilized He-Ne laser with wave length $\lambda = 0{,}6328$ mkm was used. Two beams from the laser propagated thorough a rotating optical disk in direct and reverse directions, and then they interfered. Diameter of the disk was 45 mm, thickness of the disk was 20 mm. Light fell and refracted on flat surfaces of the optical disk.

Speed of rotation of the optical disk was changed from 50 to 400 revolutions per second. The PIN photodiode was used as a photodetector.

Processing experimental data was based on defining the time of motion of interference fringes along an aperture of the photodetector.

The interferometer was in thermo-stabilized cavity with accuracy 0,1ºC.

In a result it was obtained linear dependence for interference pattern shift on speed of rotation.

Interference pattern shift was measured according to time of fringes motion along a FD aperture. Results of measurements are presented in fig.3. A measuring method is presented in works [5], [6].

Time of signal recording with one rotation frequency was 15 seconds. Thus, for example, when rotation frequency was 200 Hz it was made 3000 measurements for one point of the diagram in fig.3. To reduce low-frequency mechanical noises and high-frequency electromagnetic influence, we used filtration of the 5th order.

There are two diagrams in fig. 3. One of them is for frequency changing from minimal to maximal frequency, another that is for changing from maximal to minimal frequency. Obtained hyperbolic dependences are close to each others. It is very stable result.

The method, allowing to recalculate from time interval to IP shift, is realized with elliptical integrals of second genus and is presented in [5]. Hence, as an interferometer was adjusted for one working point of the phase curve during measurements was carried out, so the IP shift is proportional to time of fringes motion along a FD aperture in the first approximation.

As it follows fig.3 dependence for a signal on rotation frequency has a hyperbolic view. Hence the dependence differs from theoretical that when the Fizeau's effect is not taken into account.

Dependence of difference between the calculated shift without accounting the Fizeau's effect and the measured shift on velocity of rotation is presented in fig.4. The dependence is linear and it is close to the theoretical that (1). It is seen from the fig.4 that time interval of fringes motion along a FD reduces by $10 \pm 1\%$ when a period is equal to 3000 mks (it accords to rotation frequency 330 Hz). Meanwhile the expected IP shift in relation to band width is equal to $1{,}62\%$. (The calculated value is $\Delta_{\Sigma} = \Delta'_0 + \Delta' = 1{,}62 \times 10^{-2}$).

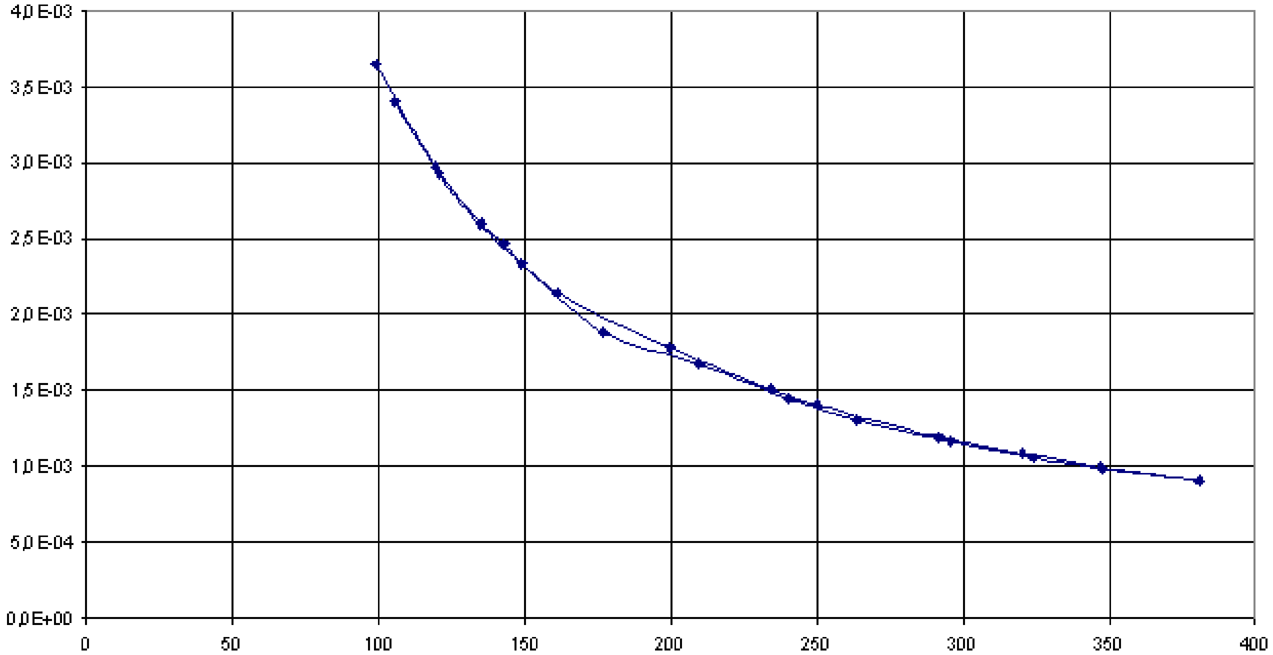

Fig.3. Dependence of motion time for the last interference fringe along photodetector (PD) aperture on rotation frequency of OD.

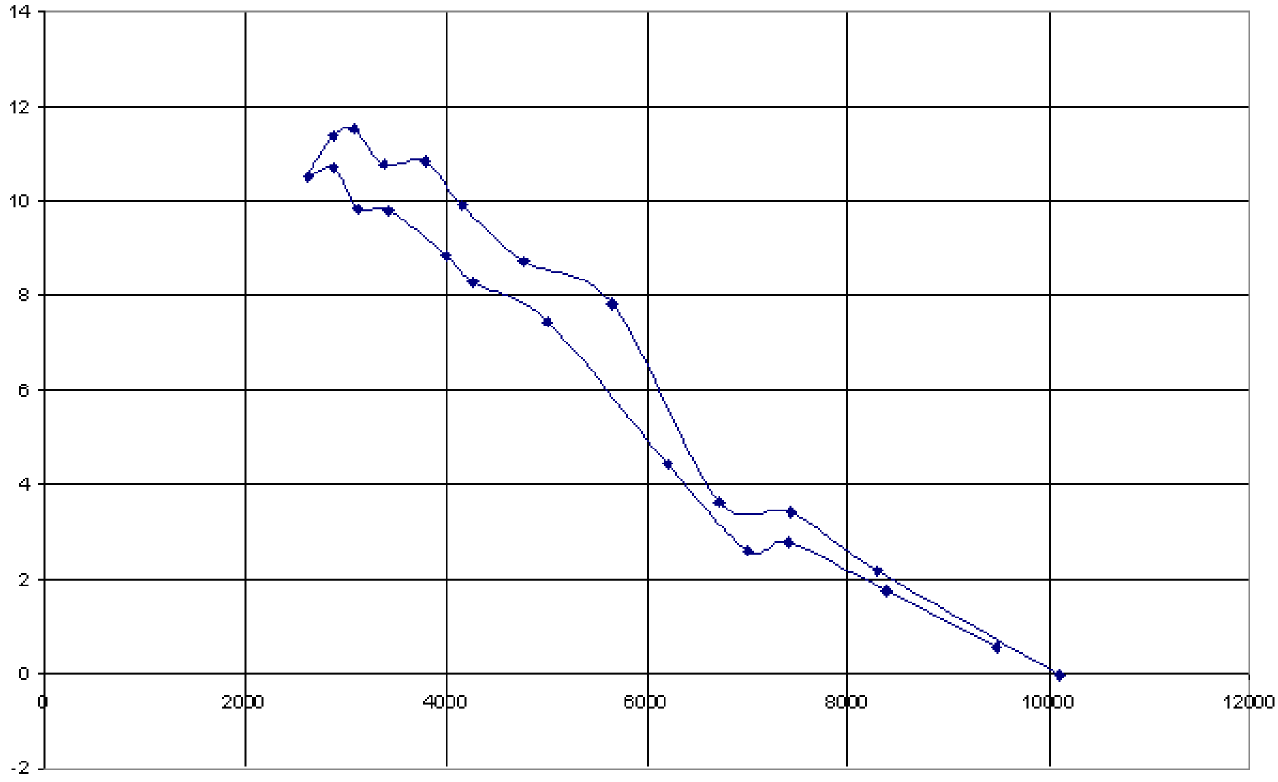

Fig.4. Dependence of relative difference between calculated IP shift without Fizeau's effect and measured IP shift (%) on rotation period (mks).

Increasing or decreasing a time interval with the fixed direction of OD rotation depends on adjustments of an interferometer. Thus, if we calibrate the interferometer, we will be able to define IP shift by altering time of interference fringes motion. Then we can solve the reverse task – to define velocity of medium motion by using time of interference fringes motion. If velocity of medium motion is given, but anisotropy appears in the experiment, so we will be able to find magnitude and direction of interferometer motion velocity in space by means of an anisotropy component, which is measured with different orientations of the interferometer in space.

Accuracy of an experiment can be estimated by means of an anisotropy component in the next manner: variation of fringes shift $\delta \approx 1{,}6 \times 10^{-3}$ corresponds to 1% of minimal measured magnitude of a signal; if we compare the magnitude with the obtained estimation of expected variation $\delta = 4{,}7 \times 10^{-6}$ due to Galaxy velocity ($\beta \approx 10^{-3}$), we can conclude that accuracy of measurements should be in 340 times higher. Thus, we could detect such value of variation of IP shift which corresponds to $\beta \geq 0{,}34$.

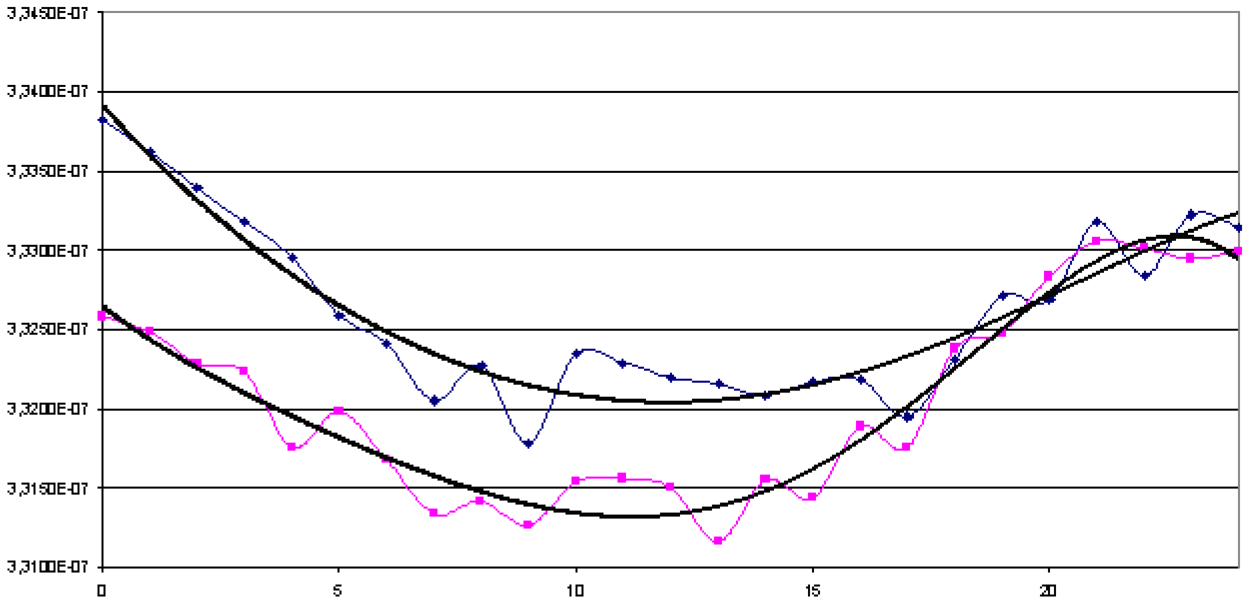

Fig.5. Dependence of signal on turn angle of the interferometer for direct and reverse rotations. Unit of axis x is equal to 15 degrees. Dark curves are as a result of spline - interpolation.

In the previous figures the results of measurements were shown for the fixed orientation of an interferometer in a laboratory. Total time for the measurements to draw a diagram was 20 minutes. A laboratory IF slightly changed its space orientation. To obtain possible dependence of a signal on spatial orientation of the interferometer we carried out an experiment for measuring a signal when the interferometer was turning within 360 degrees in two opposite directions (Fig.5). The experiment was repeated with different orientations of the platform in 15 degree interval in a laboratory reference system. Total time for all measurements to create a diagram was 50 minutes, therefore diagrams for direct and reverse rotation can be displaced one relative to other.

There are diagrams for signals, normed on rotation period of OD, and them spline – interpolations for direct and reverse rotations of the interferometer in the fig. 5.

Rotation frequency 200 Hz was chosen for measurements. Experimental data were recorded with digitization frequency 1 MHz.

As it follows from fig.5 the magnitude of drift of signal amplitude for 50 minutes was about $0{,}36\%$. Additional measurements shown that the drift of signal amplitude was proportional to time, therefore, measurements were carried out in equal intervals of time. As the laser is stabilized on frequency and power, its adjustments were the same in a twenty-four hours or in a week, so the amplitude drift is possibly linked with dynamic fatigue of material due to platform vibration. Shape of signal diagram has minimum which repeats when the interferometer is tuned in both directions. Hence, the repeated experiments for different time of a day or a night have the same shape of diagrams and minimum in its center. This points out that a signal form has probably mechanical nature and is caused by non-ideality of the rotary system. Because of availability of amplitude drift and non-ideality of the rotary system, main information should be contained in difference of signals for direct and reverse rotations of the platform with the interferometer. Hence, analysis shows that a difference signal, corrected with value of drift, is in the level of random error for the given accuracy level.

Thus, the main result of experiments is quality confirmation of linear dependence of an interference pattern shift on motion velocity of a medium. Aanisotropy of a signal wasn't detected in the first series of experiments. As error in the experiment didn't exceed $0{,}36\%$, that is less by a factor 3 than error, which used for the measured estimation δ and the value β, we can conclude, that variation δ could be found for $\beta \geq 0{,}1$. In future, it is principally important to check delectability of δ when accuracies correspond to Galaxy velocity ($\beta \approx 10^{-3}$). For the experiment we need increase accuracy of the experimental set in 2 orders, it is possible higher rotation frequency of OD, more vibro-protected system for rotating an OD, more sensitive photodetectors.

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