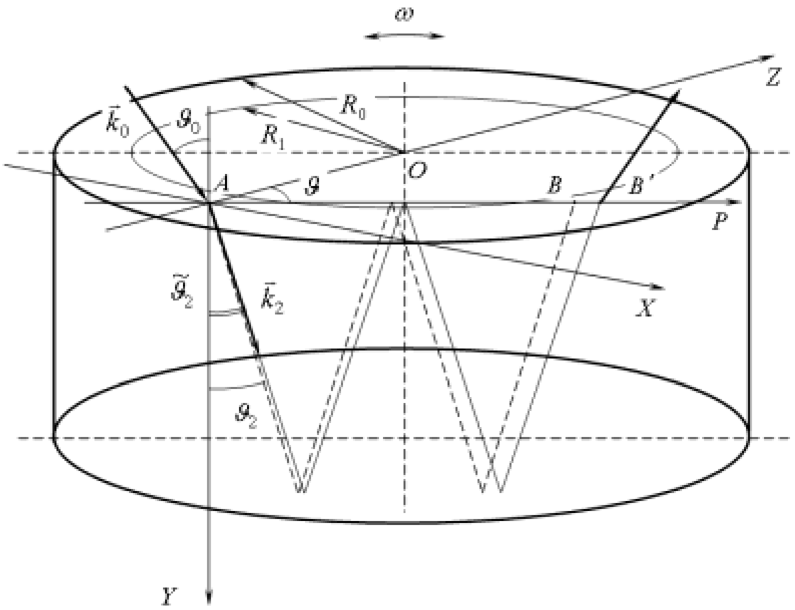
An effect of the transversal light dragging in a moving medium

In an interferometer with a moving element the difference between optical paths for two interfering beams, have been passing through the moving element in opposite directions, depends on transversal and longitudinal effects of light wave dragging. Under defined conditions the transversal dragging effect of an electromagnetic wave can be comparable with the longitudinal dragging effect. In the work a question on influence of transversal dragging effect of a flat electromagnetic wave in a rotating optically transparent medium in approximation of geometric optics is considered and parameters are calculated, when the influence has maximal value, in the work.



Let us an electromagnetic wave with a wave vector $\vec{k}_0$ is incident onto a flat surface of a rotating with angle velocity ω optical disk of a radius R_0 under an angle ϑ_0 in a plane YAP (fig.1).

Fig.1. Flat surfaces of the optical disk (OD) have reflecting coverings for increasing an optical path in a moving medium.

Top surface of OD has reflecting covering of OD with a radius R_1, the lowest surface is fully reflecting. As a result of Snell's law violation the angle of refraction ϑ_2 gets equal to $\tilde{\vartheta}_2$, and the point B of the beam exit from the disk shifts in the point B'. Distance between a point of bean incident and the disk center is equal to $OA = R$. Distance between a beam projection (an axis AP) and the disk center is $r = R\sin\vartheta$.

Difference of beam paths propagating trough the OD in opposite directions due to the longitudinal effect of light dragging is defined with the expression [7]

$$\Delta_0 = \frac{2l}{\lambda}\frac{\beta_{2n}(n_2^2-1)}{1-n_2^2\beta_{2n}^2}. \quad (1)$$

Here $\beta_{2n} = \pm V_{2n}/c$, $V_{2n} = 2\pi\nu r$, $\vec{V}_{2n}$ is OD velocity projection on AP, $l = AB' = 2\sqrt{R^2 - r^2}$, n_2 is the refraction index of OD material, $\lambda = 2\pi/k_0$. Let us to noitice that the value Δ_0 will be maximal, if $r = r_0 = R/\sqrt{2}$.

The transversal effect of light dragging will be depended on the OD thikness d

$$\Delta' = \frac{2Nd(n_2-1)}{\lambda}\left(\frac{1}{\cos\vartheta_2'} - \frac{1}{\cos\vartheta_2}\right). \quad (2)$$

Here N is number of beam passages between plane surfaces of the optical disk.

For ϑ_2' we can obtain

$$\cos\vartheta_2' = \frac{n_2\cos\vartheta_2 - \kappa_2\beta_{2n}}{\sqrt{n_2^2 - 2n_2\kappa_2\beta_{2n}\cos\vartheta_2 + \kappa_2^2\beta_{2n}^2}}, \qquad \kappa_2 = n_2^2 - 1. \quad (3)$$

In approximation $\beta_{2n}^2 << \beta_{2n}$ the expression (2) will nave a view

$$\Delta' = \frac{2Nd(n_2-1)\kappa_2\beta_{2n}}{\lambda n_2} tg^2\vartheta_2. \quad (4)$$

Total shift due to the light dragging effect, accounting that $Nd\,tg\vartheta_2 = l$, will be equal to

$$\Delta_\Sigma^\pm = \Delta_0 \pm \Delta' = (1 \pm \rho)\Delta_0 . \qquad (5)$$

Alternative of the sign depends on geometry of beams in an interferometer.

Here the parameter

$$\rho(n_2, \vartheta_0) = \frac{n_2 - 1}{n_2} tg\vartheta_2 = \frac{n_2 - 1}{n_2} \frac{\sin^2 \vartheta_0}{\sqrt{n_2^2 - \sin^2 \vartheta_0}} \qquad (6)$$

defines effectiveness of the transversal light dragging. The solution (6) is presented in the figure 2.

Let us find the maximal value of ρ^m. Let us take into account that the maximal magnitude of $tg\vartheta_2$ is limited to the incident angle $\vartheta_0 \to 90^\circ$. For the limit we have

$$\rho(n_2) = \frac{1}{n_2}\sqrt{\frac{n_2 - 1}{n_2 + 1}} . \qquad (7)$$

The given function has maximum when $n_2 = \frac{1+\sqrt{5}}{2} = 1{,}618034$. Substitution of the value into the expression (7) gives $\rho^m = \frac{\sqrt{2\left(\sqrt{5}-1\right)}}{3+\sqrt{5}} = 0{,}3$. Existence the maximum can be explained with competition of two effects: on the one hand, with growth n_2 an optical path increases, on the other hand, the angle ϑ_2 decreases and, therefore, a geometrical path in material of the OD decreases too.

Thus, the maximal magnitude of the transversal dragging effect can reach 30% from the longitudinal dragging effect, which is characterized by Δ_0, in the presented scheme on the fig.1.

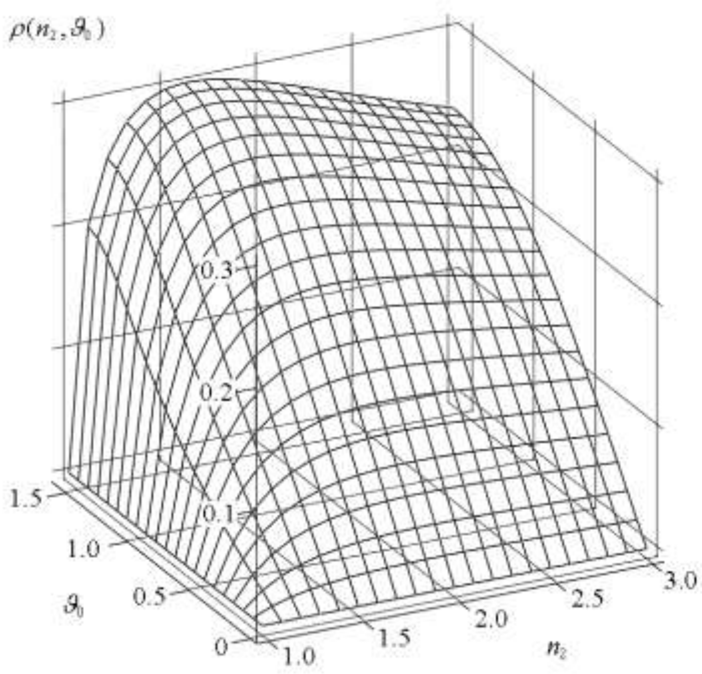


Fig. 2. Dependence of the effectiveness parameter of the transversal light dragging on refraction index n_2 of the OD material and the incident angle ϑ_0 (in radians).

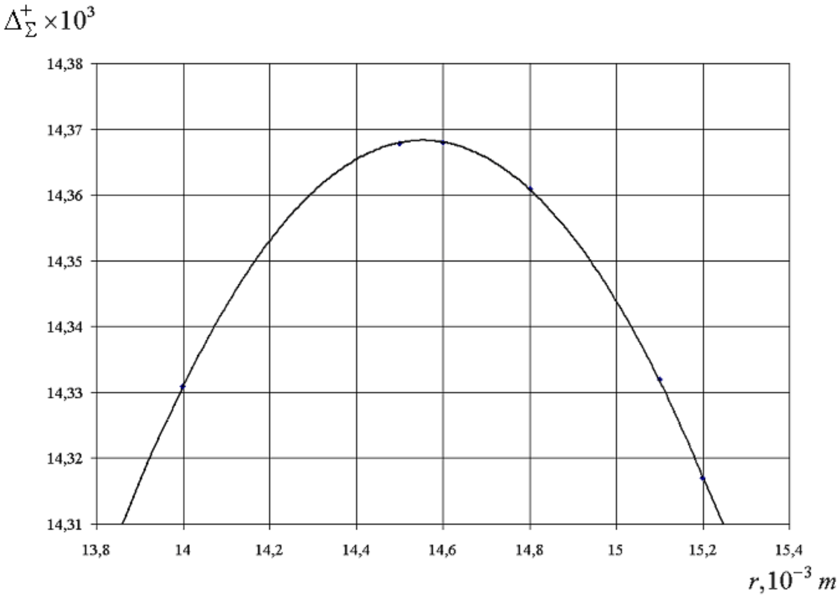


Fig.3. Dependence of the total optical path difference Δ_Σ^+ on the parameter r .

Let us find the optimal relation between r and R with accounting the transversal dragging effect. For the Δ_Σ^+ we can write

$$\Delta_\Sigma^+ = \left(1 + \alpha\sqrt{\mathrm{R}^2 - r^2}\right)\beta r\sqrt{R^2 - r^2}\ , \qquad (8)$$

here ν is the rotation frequency of the OD, $\alpha = \dfrac{2}{Nd}\dfrac{n_2 - 1}{n_2}$, $\beta = \dfrac{8\pi(n_2^2 - 1)\nu}{\lambda c}$.

Let us make estimation of variations for r to receive the maximal magnitude Δ_Σ^+. Numerical solution for (8) is presented in the figure 3 for parameters $R = 21{,}5$ mm, $d = 0{,}02$ m, $N = 3$, $n_2 = 1{,}7125$ (TF3), $\nu = 200$ Hz, $\lambda = 0{,}632991$ μkm.

From the figure 3 it follows that Δ_Σ^+ has the maximal magnitude when $r = 14{,}6$ мм instead of $r_0 = R/\sqrt{2} = 15{,}2$ mm.

Thus, it follows from the analysis that the transversal dragging effect can be equal the magnitude of the order of 30% from the longitudinal dragging effect characterized by Δ_0. The most influence the effect has when $n_2 = 1{,}618034$. Input of beams into a moving medium should be optimized taking into account the effect. The resulting influence of the effect depends on a trajectory of beams between a moving optical medium and a plane of interference pattern localization.

This calculation was published in [8].

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