LETTERS TO THE EDITORS

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Inconsistencies in the work of P Maraner

(reply to comment [*Usp. Fiz. Nauk* **186** 795 2016] on the paper "Quadratic Sagnac effect—the influence of the gravitational potential of the Coriolis force on the phase difference between the arms of a rotating Michelson interferometer (an explanation of D C Miller's experimental results, 1921–1926)" (*Usp. Fiz. Nauk* **185** 431 (2015); [*Phys. Usp.* **58** 398 (2015)])

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<u>Abstract.</u> We consider the distributions of the scalar gravitational potential of Coriolis forces in different parts of the shoulder of a rotating equal-arms Michelson interferometer. It results in a view of the very small difference between the phases of light in the shoulders of the Michelson interferometer, in comparison with the phase difference due to the quadratic Sagnac effect. It has been shown that there is an effect, discussed earlier by P Maraner, which is a higher approximation to quadratic Sagnac effect.

Keywords: Michelson interferometer, Coriolis force, gravitational potential, Earth orbital revolution

For a rotating Michelson interferometer (MI), it was shown by P Maraner [1] that light traveling through one interferometer arm acquires a certain small phase shift relative to light in the other arm; and by the present authors, that another, by far stronger effect known as the quadratic Sagnac effect (QSE), is also at work, which can explain the nonnull results of the Michelson–Morley (MM) experiment [3, 4] and its repeated versions. Included in the present *UFN* issue is P Maraner's work [5], which makes some criticisms of Ref. [2] and argues for the priority of paper [1] over paper [2].

The purpose of this note is (1) to identify what specific mistake was made by the author of Ref. [1], which prevented

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Uspekhi Fizicheskikh Nauk **186** (7) 796–798 (2016) DOI: 10.3367/UFNr.2016.02.037737 Translated by E G Strel'chenko; edited by A Radzig him from revealing the QSE; (2) to show that the effect examined in Ref. [1] is the QSE calculated to the second order in the effective rotation radii of each of the MI arms, and (3) to respond to the criticisms levelled in Ref. [5].

P.1 The key mistake made in Ref. [1] — and the reason why P Maraner failed to obtain an expression for the QSE is that, because all calculations in Ref. [1] are done in the laboratory inertial frame of reference, it is necessary to consider how the motion of the arm end mirrors of the rotating MI affects the reflection of light-something which the author of Ref. [1] failed to do. Reflection from even a linearly moving mirror leads to a number of peculiar phenomena, such as a change in the frequency of the reflected light and unequal incidence and reflection angles [6]. In his seminal paper [7], Albert Einstein circumvented these problems by employing an inertial frame of reference (IFR), co-moving with the mirror, in performing most of his calculations. This problem can also be correctly solved in a laboratory IFR, but by using Maxwell electrodynamics [6] instead of the method of geometrical optics Ref. [1] relies on. In our study [2], all calculations were performed in a noninertial frame of reference co-rotating with the MI, in which the MI mirrors are at rest.

P.2 Let us compare the results of Ref. [2] with those of Ref. [1]. From Ref. [2], the QSE is given by

$$\Delta \Phi = -\frac{L}{\lambda} \frac{\Omega^2 R^2}{c 2} \left(\cos^2 \phi \cos 2\psi - \sin^2 \phi \right), \tag{1}$$

where $\Delta \Phi$ is the phase difference between the arms of the rotating MI, *L* is the MI arm length, *R* is the MI rotation radius, i.e., the distance from the center of rotation to the split mirror (for example, Earth's orbit radius), Ω is Earth's orbital angular velocity, *c* is the speed of light in vacuum, λ is the light wavelength, ψ is the rotation angle of one of the MI arms in its proper plane relative to a straight line in this plane, and ϕ is the rotation axis. Reference [1] gives a different expression for the phase difference between the arms of a rotating MI:

$$\Delta \Phi = \Delta t \frac{c}{\lambda} = 2\sqrt{2}\pi \frac{L}{\lambda} \frac{\Omega^2 RL}{c^2} \sin\left(2\phi\right) \sin\left(\alpha + \frac{\pi}{4}\right).$$
(2)

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The angle α has the same physical meaning as the angle ψ in expression (1), (i.e., the MI rotation angle), but, in general, α and ψ are measured in different planes. Expressions (1) and (2) differ considerably in that (apart from a dimensionless factor L/λ) the arm phase difference is proportional to $\Omega^2 R^2/c^2$ in the former, and to $\Omega^2 RL/c^2$ in the latter. Because $R \gg L$, it is obvious that the QSE substantially exceeds the effect given by Eqn (2). In what follows, we consider the case where $\phi = \pi/2 = \text{const}$, i.e., the MI plane is parallel to the ecliptic plane and does not change its orientation with time. In this case, it follows from Eqn (1) that a rotation through an angle of ψ leaves the arm phase difference $\Delta \Phi$ unchanged because $\cos^2 \phi = 0$. In so doing, the effect considered in Ref. [1] is easier to separate out.

Let *l* be the varying coordinate along the MI arm length and be measured from the location of the MI split mirror (0) to the end of this or the other MI arm, where the reflection mirror is placed ($0 \le l \le L$). The length of effective radius R^{eff} which connects the center of rotation with point *l* on the MI arm is given by

$$R_1^{\text{eff}}(l) = \sqrt{R^2 + 2Rl\cos\alpha + l^2},$$

$$R_2^{\text{eff}}(l) = \sqrt{R^2 + 2Rl\cos\left(\frac{\pi}{2} - \alpha\right) + l^2},$$

where the subscripts '1' and '2' stand for the first and second arms, respectively, and α is the angle of rotation of the first MI arm about the radius *R*. The average value of *l* is L/2; hence, the average values of the effective radii are expressed as

$$R_1^{\text{mid}} = \sqrt{R^2 + RL\cos\alpha + \frac{L^2}{4}},$$

$$R_2^{\text{mid}} = \sqrt{R^2 + RL\cos\left(\frac{\pi}{2} - \alpha\right) + \frac{L^2}{4}}, \quad R_{1,2}^{\text{min}} \equiv R.$$

The quantities $R_{1,2}^{\text{mid}}$ determine the average time retardation in the first and second MI arms due to the gravitational potential of the Coriolis force in the co-rotating frame of reference, and the light travel time along the MI arms in forward (superscript '+') and backward (superscript '-') directions for circular motion at angular velocity Ω are as follows [2]

$$t_{1,2}^{\pm} = t \sqrt{1 \mp \frac{2\Omega R_{1,2}^{\text{mid}}}{c}},$$

where t = L/c is a single-trip light travel time through an MI arm in the absence of rotation. The difference Δt in the light travel times in forward and backward directions along the first and second MI arms is $\Delta t = t_2^+ + t_2^- - (t_1^+ + t_1^-) =$ $(\sqrt{2} \Omega^2 R L^2/c^3) \sin(\alpha - \pi/4)$, giving the following expression for the optical phase difference between the MI arms as measured in units of the interference fringe width (2π rad):

$$\Delta \Phi = \Delta t \frac{c}{\lambda} = \sqrt{2} \frac{L}{\lambda} \frac{\Omega^2 R L}{c^2} \sin\left(\alpha - \frac{\pi}{4}\right). \tag{3}$$

Equation (3) differs from Eqn (2) only by a factor 2π , the reason being that while in Ref. [2] and in the present work the expressions for $\Delta \Phi$ are given in terms of the interference fringe width, Ref. [1] uses radians. The difference in the signs of the phase difference is explained by the distinction in labeling the MI arms in formulas (3) and (2).

Thus, we have shown that the slight difference in the effective radii R^{eff} , which was ignored in Ref. [2], produces a small correction to the results of Ref. [2], or, equivalently, gives a second-order approximation in R^{eff} , which is just the weak effect considered in Ref. [1].

P.3 Now let us respond to the major criticisms and objections levelled by Ref. [5] against our work [2]. Below, quotations from Ref. [5] are given italicized, and references within them are numbered as they are therein.

P.3.1 Ref. [5]: ... the phase shift induced in a uniformly rotating, arbitrarily oriented, equal-arm Michelson interferometer had already been calculated in full generality in work [5] (for some reason belatedly misquoted as reference [53] in paper [1]).

As shown in P.1, there was a mistake made in Ref. [1], and the results themselves of Ref. [1] are, as shown in P.2, a correction of higher order in the length of the effective radius of rotation R^{eff} to the results of Ref. [2]. As for the order of referencing, it is up to the authors, all the more since, as shown in Ref. [8], P Maraner's work [1] is by no means the first unsuccessful attempt to invoke MI rotation to explain the nonzero results of the Michelson–Morley experiments and of their classic repetitions.

P.3.2 Ref. [5]: ... in the limit of very large radii of rotation R, with the speed of rotation $V = \Omega R$ kept constant, a uniform rotation approaches an inertial motion, and the phase shift in an equal-arm Michelson interferometer should cancel correspondingly. This is the case for formula (2), which approaches zero as 1/R. It is not the case for formula (1), which remains constant. Consequently, the result obtained by Malykin and Pozdnyakova seems to me to contradict the Special Theory of Relativity.

The transformation of a noninertial rotating frame of reference into an IFR at $\Omega R = \text{const}$ and $R \to \infty$ is a frequently used assertion by Special Relativity opponents. Its being true would rule out the existence under these conditions of, for example, the Sagnac effect [9, 10], which only occurs in a noninertial rotating frame of reference.

P.3.3 Ref. [5]: Coriolis forces are velocity-dependent interactions completely analogous to Lorentz forces in their mathematical structure [10]. As such, they cannot be described in terms of a scalar potential and can only be derived by a vector potential. Even if in other circumstances the authors have claimed that "the notion of scalar potential may be introduced for such forces, with certain constraints and reservations" [11], in no case do Coriolis forces induce time dilation.

The scalar potential of the Coriolis forces, similar to that of any other force, causes a retardation of time and affects the propagation of light [11]. As Einstein noted in his conversation with R S Shankland on February 2, 1952, "... All accelerations of such a type, including Coriolis force-related ones, are totally indistinguishable from gravity." [12] In particular, this potential has been used in obtaining correct magnitudes of the Sagnac effect in a reference frame corotating with a ring interferometer [9, 10] and a ring laser [13]. Whatever the nature of the force, the scalar potential U is subject to the restriction $U \ll c^2$ [11]. For any type of rotating optical interferometer, including an MI, this condition is thoroughly satisfied, because under large angular velocities the interferometer base will inevitably be broken apart by centrifugal forces.

P.3.4 Ref. [5]: ... As far as Miller's experimental results are concerned, we can remain satisfied with the largely accepted analysis of Shankland and collaborators [4].

D C Miller performed his experiments [14] on a windy mountain top, with the interferometer deployed in a light wooden shed with a tarpaulin roof and tarpaulin-curtained window openings-to make it easier for the 'ether' wind (and, it can be assumed, regular wind) to pass. One cannot therefore exclude the possibility (suggested in Ref. [15]) that the measurements of Ref. [14] were influenced by temperature effects. But MM's experiments, both themselves and their classical repetitions, were performed in deep basements at a constant temperature. For example, in the experiments by Joos [16], the MI base was made of molten quartz possessing very low thermal expansion and housed in a hermetic air evacuable silumin container, the whole facility being mounted in a basement. Still, both Refs [3, 4] and Ref. [16] revealed a periodic change in the phase difference between the interferometer arms when turning MI.

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Notes added in proof

In his paper [5], P Maraner makes two assertions which are, in our opinion, faulty:

(1) The quadratic Sagnac effect does not exist; what does exist is only a much weaker effect he predicted earlier [1]. To confirm this, he performed GR-based recalculations [17] of the results of Ref. [1].

(2) For large values of the ring interferometer radius R, and for $\Omega R = \text{const}$, where Ω is the angular velocity of the rotating interferometer, the Sagnac-effect-induced phase difference between oppositely propagating waves tends to zero.

The latter assertion is intended to disprove the validity of STR and was first made by him in Ref. [18]. An analysis of errors made in the notes to Ref. [5] is beyond the scope of the present note. We limit ourselves to saying that a critical analysis of P Maraner's first erroneous assertion—and hence of his work [1], is carried out in the present communication and will be presented in more detail in Ref. [19]. A critical analysis of P Maraner's second assertion (and, hence, of his work [18]), as well as a critical analysis of his work [17], will be the subject of a separate discussion paper [19].

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