

LETTERS TO THE EDITORS

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Supplement to 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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Abstract. 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)]) is amended and supplemented with information concerning earlier work on the influence of rotation on Michelson–Morley's nonzero results.

Keywords: Michelson interferometer, Coriolis force, gravitational potential, orbital rotation of Earth, Synge–Gardner effect

One can conclude from our recent paper [1] that the rotation influence on the nonzero results of Michelson–Morley's (M – M) and subsequently repeated experiments was considered for the first time in 2014 in article [2]. Actually, as our latest research has shown, such attempts were made earlier, albeit, without much success. Nevertheless, these attempts are noteworthy, because the researchers were thinking in the right direction.

The first physicist to draw attention to the rotation influence on the results of the M – M experiments back in 1898 was a researcher from Australia, W Sutherland (1859–1911) [3] (see also his short report [4]). Sutherland showed that, due to the orbital revolution of Earth, Michelson interferometer (MI) mirrors have time to slightly turn, while the light travels along the MI arms, which results in an additional phase shift. There are no equations or numerical estimates in Refs [3, 4] and Sutherland only states that the effect discussed must worsen the measurement accuracy of the M – M experiments.

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In 1952, a famous Irish mathematician and physicist J L Synge (1897–1995), considered this problem [5, 6] by using the hypothesis of another Irish mathematician, J Gardner (1926–2009) [7]. The hypothesis [7] was an attempt to solve the P Ehrenfest (1880–1933) paradox about the impossibility of a rotating perfectly rigid body to exist in the framework of the Special Theory of Relativity (STR). Gardner made an assumption that if one drew a polar coordinate grid on a motionless circular disc (concentric circles and radii starting from the origin), the circles would maintain their shape and size during rotation, while the radii would bend towards the direction opposite to the rotation, similar to the arms of a spiral galaxy. Based on this hypothesis, J L Synge made a conclusion [7] that if one of the MI arms is oriented along the bent radius of the disc and the other one perpendicular to it, then an additional phase difference between the MI arms should take place and its value, in his opinion, would be (in our notation)

$$\Delta\Phi = \frac{L}{\lambda}\,\frac{\Omega R}{c}\,\sigma \sin(2\zeta)\,, \tag{1}$$

where σ is the offset of the MI rotation axis from the vertical, and ζ is the angle between the MI arm whereat the telescope for observation of the interference fringes is installed and the northeast direction. It follows from formula (1) that if the MI rotation axis is strictly vertical, then $\sigma = 0$ and the 'Gardner–Synge effect' does not take place. We should also note that an expression for $\Delta\Phi$, found in paper [6], gives the result that is two times larger compared with Eqn (1). Moreover, this phenomenon is qualitatively illustrated in paper [6] by using world lines of two counterpropagating light pulses in the MI arms.

The assumed Gardner–Synge effect has a first order in $\Omega R/c$ and, unlike the quadratic Sagnac effect discussed in review [1] and proportional to $\Omega^2 R^2/c^2$, it has to be relatively high, because in real conditions $\Omega R/c \ll 1$. Synge decided to explain Miller's experiments [8] by invoking his results. In order to equate the value of $\Delta\Phi$, calculated using expression (1), to the experimental results [8], Synge had to take into account only the rotation of Earth around its axis, and choose $\sigma = 1.6 \times 10^{-3}$ rad [6].

In the same year of 1952, famous English physicists R W Ditchburn and O S Heavens performed an experimental verification of the Gardner–Synge effect [9]. They fixed the MI axis in the chuck of a drill at the angle of $\sigma = 45°$ to the horizon and changed the angle ζ by rotating the MI around its axis. Of course, the Gardner–Synge effect was not observed [9] due to the fact that Gardner's hypothesis [7] is wrong, and its discussion goes beyond the scope of this supplement.

However, in 1956, Synge considered again the Gardner–Synge effect to be a qualitative illustration, using the world lines of two counterpropagating light pulses in the MI arms [10]. In 1960, he attempted to solve this problem once again by using the so-called method of differential chronometry in the Fermi 3-space [11]. Quite cumbersome calculations performed in this book did not help Synge to derive a concrete expression for the phase difference between the waves in the arms of the rotating MI. At the end of Section 11.8 (mistake in the Russian language text) of his monograph [11], he pessimistically stated: "This is disappointing, but there is a grim satisfaction in pushing the theory of the famous Michelson–Morley experiment to the bitter end."

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