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Analysis of the Phase Difference in a Fiber-Optical Conveyor

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The experiments with a conveyor connected to a non-rotating fiber optic gyroscope (FOG) are described in [1], [2]. When the FOG moves rectilinear with constant speed V relative to the conveyor, a fringe shift proportional to V arises in the interferometer. This discovery leads to creating a nanoscale-sensitivity linear motion sensor. However, the authors' explanation of the experiments and of the discovered effect is incorrect. Their claim that these experiments prove a generalization of the Sagnac effect includes translational motion is also incorrect. The assumption that the “rotational” Sagnac effect is a special case of their discovery, gives rise to the erroneous claim that their device can identify Earth's rotation and may be used for a crucial test of light-speed constancy [2].

The FOG includes a light source, fiber-optical loop and screen. R. Wang connected his fiber-optical conveyor FOC to the FOG. It includes two wheels with immovable axes and an additional fiber-optical loop with N turns of fiber (Fig.1). R. Wang states: “A single mode fiber loop with different configurations was added to the FOG, which was calibrated for the added length. The loop includes significant portions of fiber segments that move linearly. The function of the FOG in this experiment is to transmit and receive the counter-propagating light beams and to detect the phase differences between the two light beams”.

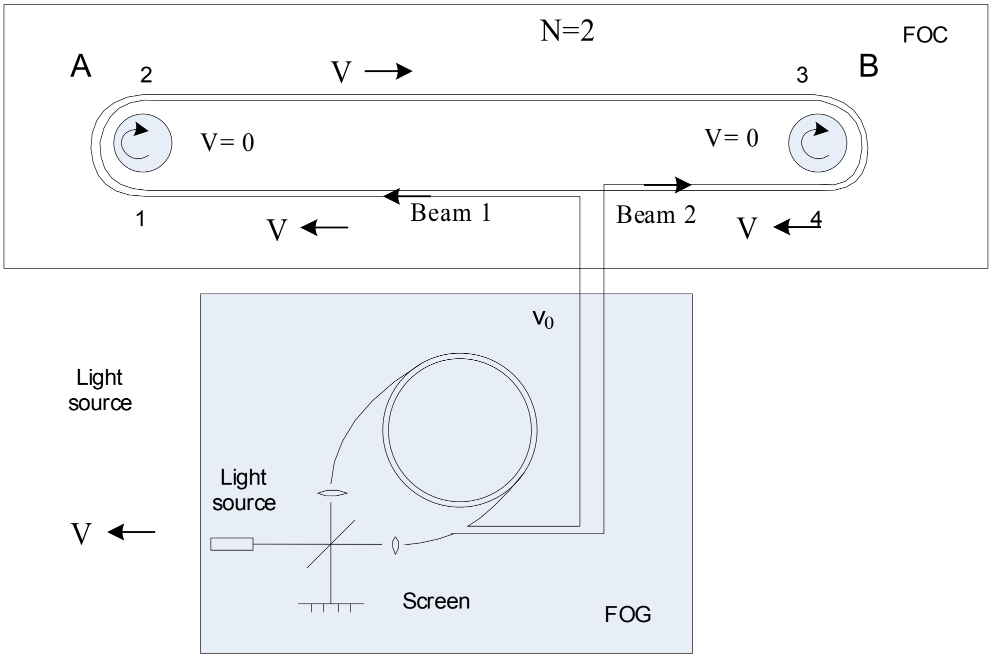

Fig.1

It is shown below that the experiments with a fiber-optic conveyor (FOC) are not related to the Sagnac effect. In these experiments, counter-propagating beams **change their frequencies** while they pass from one inertial frame connected with fiber-optical gyroscope (FOG) to another frame (connected with optical fiber linearly moving relative FOG). Beams travel through the fiber, moving relative to the FOG, with different frequencies and as result, the phase deviation arises on this part of the conveyor. When the beams pass from the moving fiber to the frame of the FOG, they change their frequencies again and interfere in FOG with identical frequencies.

When the fiber-optic conveyor is at rest (V=0), the beams enter and exit the fiber loop without any phase deviation and the fringe shift in the interferometer is zero. In motion, the fiber optic gyroscope and lower portion of the fiber move left with speed V while the upper portion of the fiber moves right at the same speed. (Fig.1). The phase deviation arises when the gyroscope and fiber move with speed V.

Because the gyroscope does not rotate, the phase deviation arises only in the fiber-optical loop and "any segment of the loop contributes to the phase difference between the two counter-propagating light beams in the loop".

The authors analyzed the propagation of light in an optic fiber loop in the same way as identified in reference [3] where the Sagnac effect is analyzed according to the Fizeau experiment. That is, the authors presuppose that the beams travel relative to the moving fiber, not with identical speed $\frac{C}{n}$ but with different speeds $\frac{C}{n}+V\left(1-\frac{1}{n^2}\right)$ and $\frac{C}{n}-V\left(1-\frac{1}{n^2}\right)$.

In order to examine the time differences in the parts of fiber moving with different speeds, the authors developed a fiber optic "parallelogram" where the top arm moves with the conveyor and the bottom arm is stationary (Fig.2). According to the authors, "the two sidearms, being flexible, are kept the same shape so that the phase differences in these two sidearms cancel each other" and there is no phase difference in the bottom stationary arm. Therefore, "the detected phase difference is contributed solely by the motion of the top arm" [2].

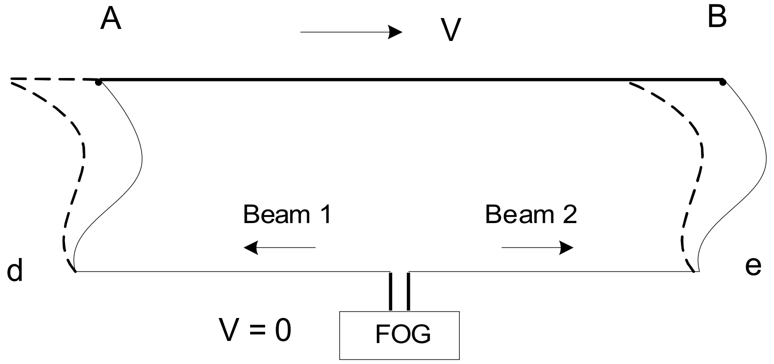

Fig.2

As shown below, the arrangement of Fig.2 in principle, does not differ from the scheme of Fig.1 and the effect discovered by the authors is not only **not** compensated in the sidearms of moving fiber optic loop but, on the contrary, arises exactly because of these sidearms.

In a fiber-optic conveyor, the light source and all parts of the fiber are moving (Fig.1). The analysis is greatly simplified if all processes are considered relative to the inertial frame connected with the fiber-optic gyroscope. That is, instead of the arrangement in Fig.1, we consider an equivalent arrangement, Fig.3 in which the gyroscope and lower parts of fiber (to points 1 and 4) are immovable and the wheels are rolling relative to the immovable part of the fiber. That is, they not only rotate but move with speed V to the right. The upper part of the fiber moves in this scheme to the right with speed 2V.

It is already possible to understand intuitively that the frequency of beam 1 going from point 1 of the immovable fiber to point 2 moving relative to point 1 with a speed 2V, decreases. Because of the Doppler effect, its frequency changes from ν_0 to $\nu_1=\nu_0(1-\frac{2V}{C})$ and beam 1 covers the distance 2-3 between the wheels A and B with the constant frequency $\nu_1<\nu_0$. Moving from point 3 to point 4,

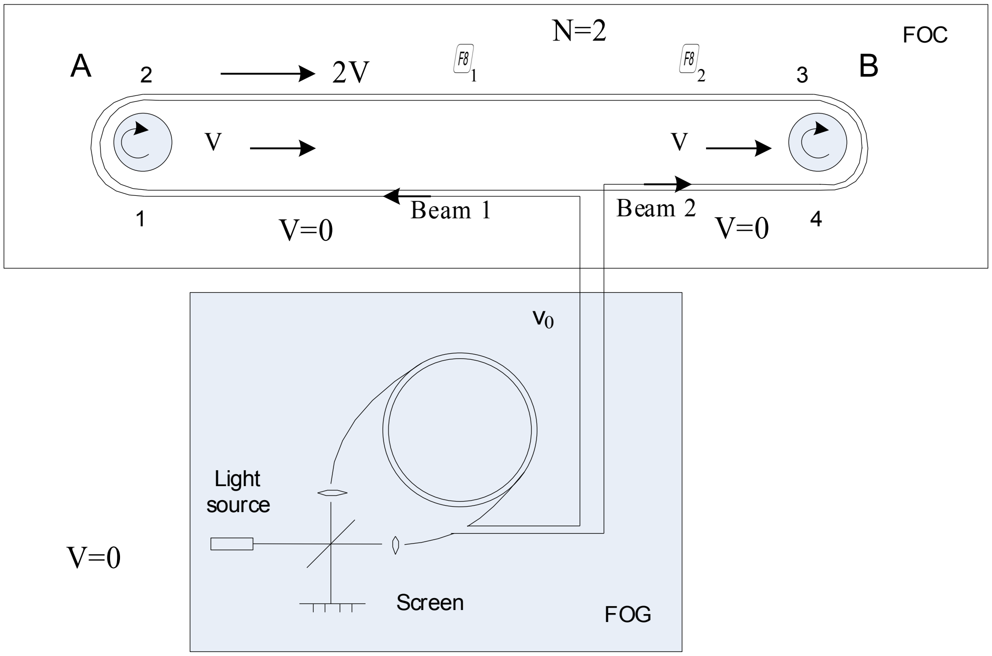

Fig.3

beam 1 increases its frequency until $\nu_0(1-\frac{2V}{C})(1+\frac{2V}{C})=\nu_0(1-\frac{4V^2}{C^2})$ which for all practical purposes, is equal to ν_0 .

Analogically, beam 2 going from the immovable point 4 to point 3 of the moving fiber, increases its frequency from ν_0 to $\nu_2=\nu_0(1+\frac{2V}{C})$ and covers the same distance 3-2 between wheels B and A with a frequency $\nu_2>\nu_0$. Moving from point 2 to point 1, beam 2 decreases frequency until the same value $\nu_0(1+\frac{2V}{C})(1-\frac{2V}{C})=\nu_0(1-\frac{4V^2}{C^2})$ as beam 1 is reached. That is, beams 1 and 2 reach the interferometer with identical frequencies.

The beams travel relative to to fiber with identical speeds $\frac{C}{n}$ and exit the loop simultaneously. But because the phase deviation arises on part AB where the beams pass with different frequencies, the fringe shift arises in interferometer.

The arrangement in Fig.3 is equivalent to the arrangement of the fiber-optic conveyor (Fig.1), but in fact, it coincides with the fiber-optic "parallelogram" of Fig.2. That is, the "parallelogram" does not differ in principle from the main arrangement of the conveyor in Fig.1.

Therefore the change of frequencies arising when beams enter the upper part of the optic fiber loop in schemes Fig.1 and Fig.2 can be shown more clearly by the example of the fiber-optic "parallelogram" if a little change is introduced as shown in Fig.4.

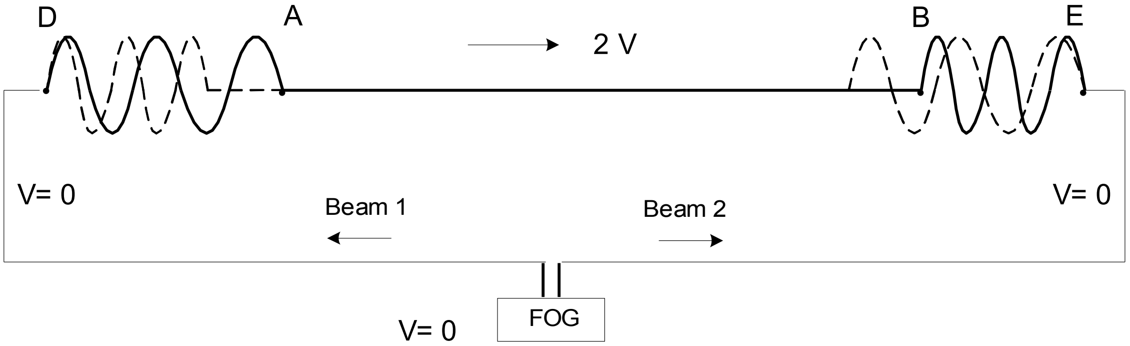

Fig.4

The beams exit from the gyroscope with an identical frequency ν_0 . They travel in the inertial frame connected with the immovable parts of the fiber up to points D and E and therefore reach these points with the same frequency ν_0 .

To point A receding from D with speed 2V, beam 1 travels in the fiber with an acceleration. That is, the photons are in a non-inertial frame when traveling from D to A and their frequency decreases. Knowing that point A moves with constant speed 2V, we can say that the frequency of the photons changes from ν_0 to $\nu_1=\nu_0(1-\frac{2V}{C})$.

From A to B, the photons of beam 1 move in the inertial frame with a constant frequency $\nu_1<\nu_0$. Over the distance BE, the photons travel in the fiber which is moving more slowly and increases its frequency to $\nu_0(1-\frac{4V^2}{C^2})$. Neglecting the second order, we can take this frequency equal to ν_0 . Because point B moves toward the beam 2, in the distance from E to B, the frequency of photons increases from ν_0 to $\nu_2=\nu_0(1+\frac{2V}{C})$ and from B to A, the photons of beam 2 travel with constant frequency $\nu_2>\nu_0$. When they move from A to D, their frequency decreases to $\nu_0(1-\frac{4V^2}{C^2})$ equal to the frequency of the photons of beam 1. The value of the fringe shift in the interferometer is determined by the phase deviation arising in beams 1 and 2 while they cover the distance between points A and B.

The above analysis shows the fallacy of the authors that the discovered effect is a generalization of the Sagnac effect to rectilinear motion. This effect has no relation to the Sagnac effect. It is explained by phase deviations arising in the beams on rectilinear moving part of the fiber because the frequencies of the beams change when beams pass, moving with a acceleration on curvilinear parts of the fiber.

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3. H.J. Arditty & H.C. Lefèvre, “Sagnac Effect in Fiber Gyroscopes”, Optical Lett. **6**, 401-403 (1981).

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