Fiber Optic Sensor for Measuring Rotation

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Abstract

The effect of the angular velocity on the interference pattern of Mach-Zehnder interferometer by using Sagnac effect had been investigated in this study.

This interference pattern was produced from the interference of the two laser beams propagated through the two arms of the interferometer.

The two arms consist of optical fiber wounded in circular shape. Each laser beam propagates in opposite direction to the other. When the system was rotated, a time difference between these two laser beams was produced.

Different angular velocities (1.5°/sec,3°/sec,4.5°/sec, and 6°/sec),different diameters of turns (0.22m,0.4m,0.6m,and 0.75m) and different lengths of optical fiber (2.8m,12.8m) were used to study the effect of each on the number of fringes .It has been found that any increase in each of the angular velocity, length of optical fiber and diameter of turns leads to an increase of the number of fringes.

Keywords: Mach-Zehnder interferometer, Sagnac effect, Angular velocity, Optical fiber sensor, Rotation sensor.

Introduction

Fiber optic rotation sensor, used in the present work, is a type of phase sensor depending on Sagnac's interferometer. This interferometer is based on two light beams propagating along opposite direction then recombined again as shown in Fig.(1), the phase shift in this interferometer is generated by rotating this system. The phase difference induced by rotation in Sagnac interferometer is called Sagnac effect. [1, 2, 3].

This optical interferometer uses a single-mode optical fiber to ensure that; the phase difference in this interferometer can be only induced by rotation. [4,5]

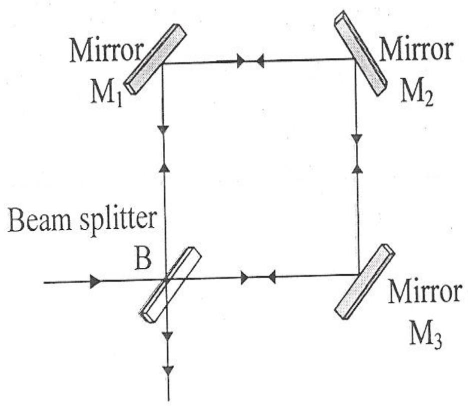

Fig. (1) Sagnac's experiment.

Sagnac's interferometer used in the present work is Mach-Zehnder interferometer based on Sagnac effect. If a disc of radius R is rotating about an axis perpendicular to the plane of the disc with angular velocity Ω, the optical path difference ΔL, experienced by light propagating in opposite directions along the perimeter of the disc as shown in Fig.(2).[1,6]

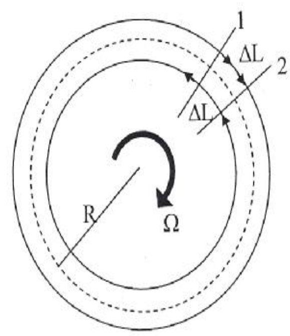

Fig.(2) Path difference in rotation disk.

Theoretical Concepts

If the time of the period of the light propagating along the perimeter of the disc without rotation is given by

$$T=\frac{2pR}{c} \quad .... (1)$$

where R is the radius of disc and c is the speed of light in vacuum. With rotation the time of one period will depend on the direction of rotation and will be as follows:

$$\left.\begin{aligned} T_{+} &= \frac{2pR}{c+\nu} \\ T_{-} &= \frac{2pR}{c-n} \end{aligned}\right\} \quad \text{..} \ (2)$$

where ν is the liner speed of position 1.
Hence the time difference ΔT will be given by

$$\Delta T = T_{+} - T_{-} \quad \text{..}(3)$$

Substituting equation (2) into equation (3), ΔT becomes:

$$\Delta T = \frac{2pR}{c+\nu} - \frac{2pR}{c-n}$$

$$\Delta T = \frac{-4pRn}{c^2 - \nu^2}$$

Sine $c^2 >> n^2$ & n =RΩ
Then the time difference for many turns will be given by

$$\Delta T = \frac{4pR^2 n\Omega}{C^2} \quad \text{...}(4)$$

where n is the number of turns of optical fiber coil
The path difference ΔL is given by

$$\Delta L = \Delta T \times c \rightarrow \Delta L = \frac{4pR^2 n\Omega}{c} \text{.......................}(5)$$

If L is the length of the fiber (L=2πR×n) and D is the diameter of the disc (D=2R).
Then

$$\Delta L = \frac{DL\Omega}{c} \quad \text{..}(6)$$

To calculate the theoretical number of fringes

$$\Delta L = N \times \lambda \quad \text{..}(7)$$

where N is a theoretical number of fringes and λ is the wavelength of the laser source.
From equation 5 & 6, the theoretical number of fringes is given by

$$N = \frac{DL\Omega}{l c} = \frac{4pR^2 n\Omega}{l c} \quad \text{.................................}(8)$$

Experimental Setup

A He-Ne laser was used as a source (λ=632.5 nm) and a two different length of single mode directional coupler optical glass fiber (2.8m & 12.8m) was used as a transmission medium. This type of optical fiber consists of a beam splitter, which splits the input signal to two outputs, 50% for transmission signal and 50% for reflection signal.

The Core/ Cladding diameter is 70 /125μm with Refractive indices of Core/ Cladding is 1.4514/ 1.4469.

2-2-4 Interference System

The system used in the present work is optical fiber Mach-Zehnder interferometer This interferometer Figure 3 consists of beam splitter in the directional coupler region to split the input laser to two beams, each one of them propagate in one arm of the optical fiber interferometer and recombined again by the second beam splitter which is placed at the end of the two arms.

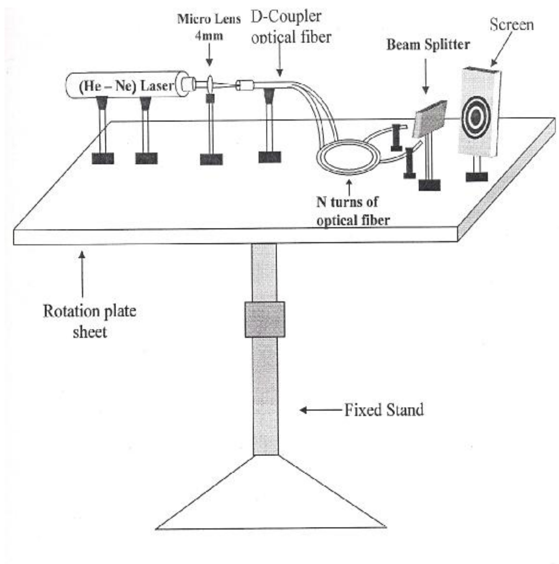

Fig.(3) The Experimental Setup Configuration.

Result & Discussion

Optical Fiber with Length (2.8m)

The optical fiber used in Mach-Zehnder interferometer arms winding in different diameters (0.75 m,0.6 m, 0.38 m , 0.23m) for each diameter the system was rotated with three different angular velocities (1.5 °/sec, 3 °/sec ,4.5 °/ sec , 6 °/sec).

The Variation in the No. of Fringes as a Function of Different Angular Velocities

If the diameter of the fiber winding (D) is fixed then the variation in the number of fringes (N) is measured as a function of the change in the angular velocities (Ω).

These are presented in the four Figs. (4, 5, 6&7). The diameter of the winding of these figures are successively fixed at (0.75m), (0.6m), (0.4m) and (0.22m).The theoretical line was found using equation 8.

N=Constant * Ω

The constant= $\frac{DL}{lc}$

In these figures, increasing the angular velocity at fixed diameter of turns produces an increase of the number of fringes because increasing of the angular velocity produces increasing in the time delay (ΔT) of the period of the laser propagating along the perimeter of the turn and creating path difference (ΔL) between the two opposite direction of laser propagation as given in equations 5, 7.

N= (ΔT × c)/λ

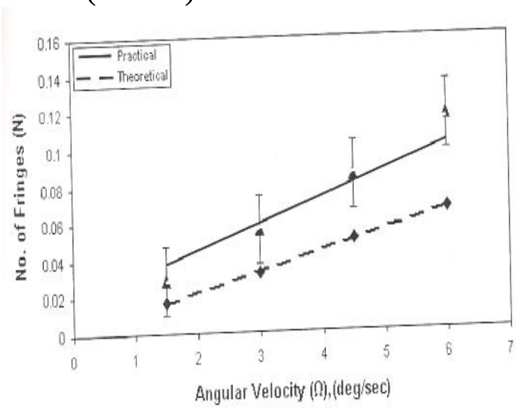

Fig.(4) Variation of number of fringes with difference angular velocities for length of optical fiber (L=2.8m) and diameter of turn (D=0.75m).

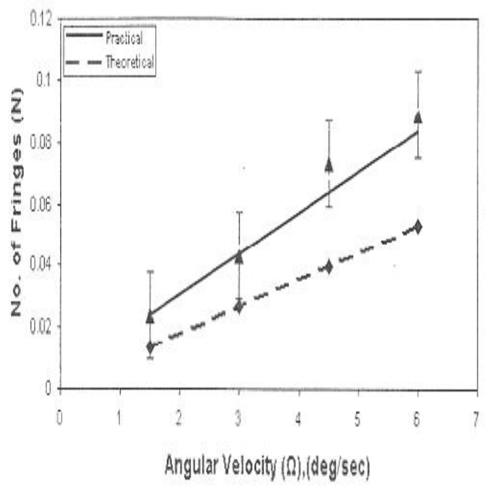

Fig.(5) Variation of number of fringes with difference angular velocities for length of optical fiber (L=2.8m) and diameter of turn (D=0.6m).

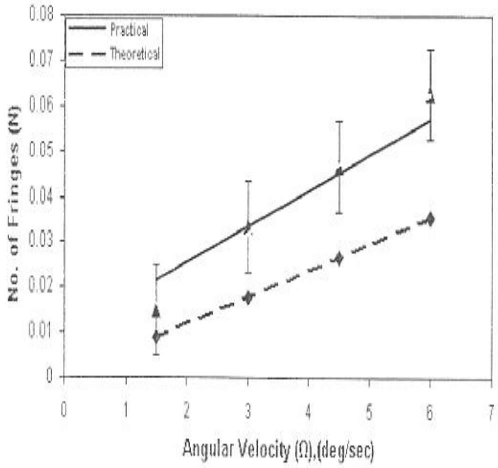

Fig.(6) Variation of number of fringes with difference angular velocities for length of optical fiber (L=2.8m) and diameter of turn (D=0.4m).

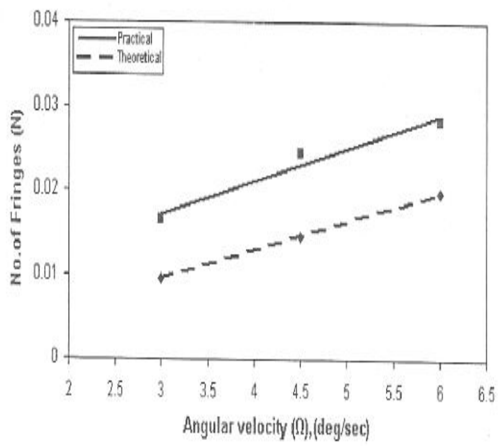

Fig.(7) Variation of number of fringes with difference angular velocities for length of optical fiber (L=2.8m) and diameter of turn (D=0.22m).

The Variation in the No. of Fringes as a Function of Different Diameters

If the angular velocity(Ω) is fixed , variation in the number of fringes(N) is function of the change in the diameter(D) of turns as shown in these four Figs. (8, 9, 10 & 11). The fixed angular velocities of these figures are successively (1.5°/sec,3°/sec, 4.5°/sec,6°/sec) .The theoretical value is calculated from equation 8 .

N=Constant *D

The constant= $\frac{\Omega l}{lc}$

Increasing in the diameter of turn in these figures produces an increase in number of fringes because the increase in diameter of turn create an increase in the path difference between the two opposite direction of propagation and consequently increase the number of fringes.

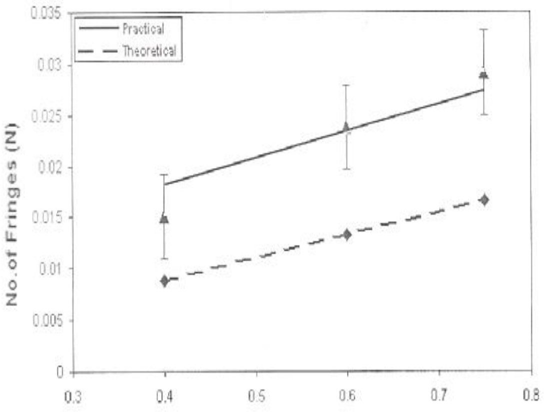

Fig.(8) Variation of number of fringes with diameter of turns of optical fiber for angular velocity (Ω=1.5 deg/sec) and length of fiber (L=2.8m).

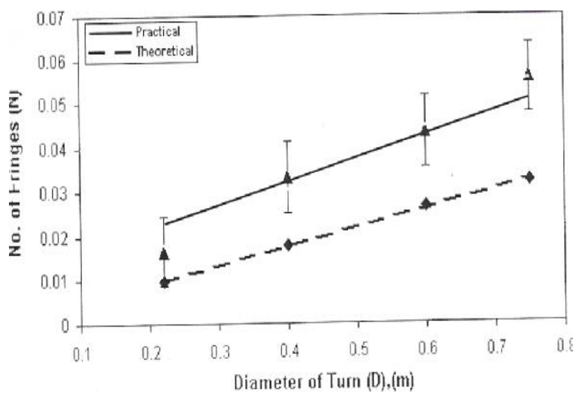

Fig.(9) Variation of number of fringes with diameter of turns of optical fiber for angular velocity (Ω = 3 deg/sec) and length of fiber (L=2.8m).

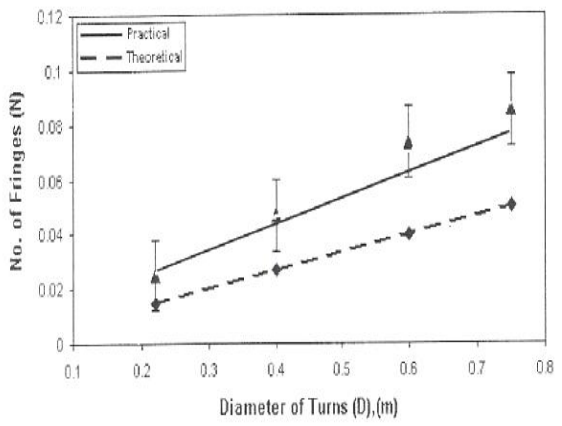

Fig.(10) Variation of number of fringes with diameter of turns of optical fiber for angular velocity (Ω= 4.5 deg/sec) and length of fiber (L=2.8m).

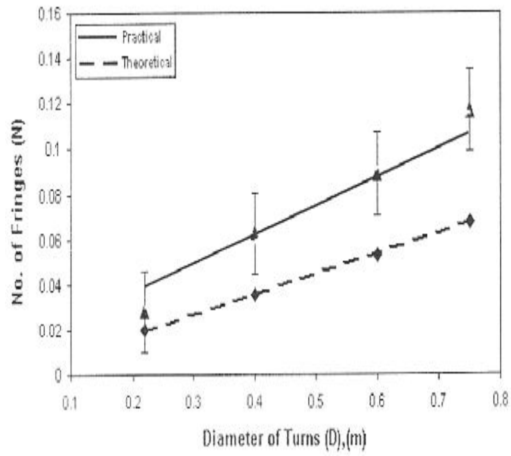

Fig.(11) Variation of number of fringes with diameter of turns of optical fiber for angular velocity (Ω=6 deg/sec) and length of fiber (L=2.8m).

Optical Fiber with Length (12.8)

The winding of The optical fiber used in Mach-Zehnder interferometer arms is of diameters (0.75m,0.6m,0.4m,and o.22m) for each diameter the system was rotated with four different angular velocities (1.5°/sec, 3°/sec, 4.5°/sec, and 6°/sec)

The Variation in No. Fringes as a Function of Different Angular Velocities

If the diameter (D) is fixed then the variation in the number of fringes (N) is function of the change in the angular velocities(Ω) as shown in Figs. (12, 13, 14 & 15).

The diameters of winding of these figures are fixed successively at(0.75m), (0.6m), (0.4m) and (0.22m),the relationship between the number of fringes and change in the angular velocity is similar to the relation for fiber length 2.8 m. The increasing in the length of the optical fiber (L) produces an increase in the number of fringes as shown in equation 8

$$N=\frac{DL\Omega}{lc}$$

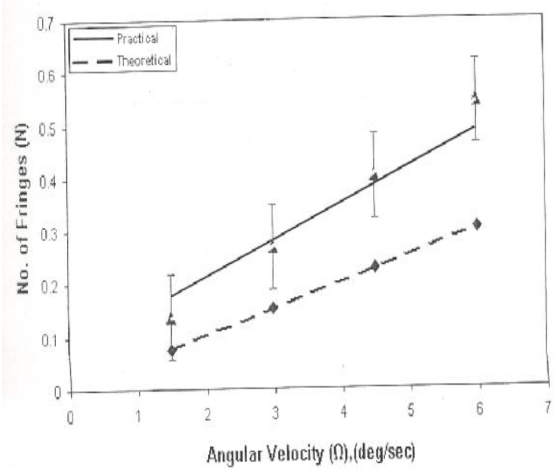

Fig.(12) Variation of number of fringes with difference angular velocities for length of optical fiber (L=12.8m) and diameter of turn (D=0.75m).

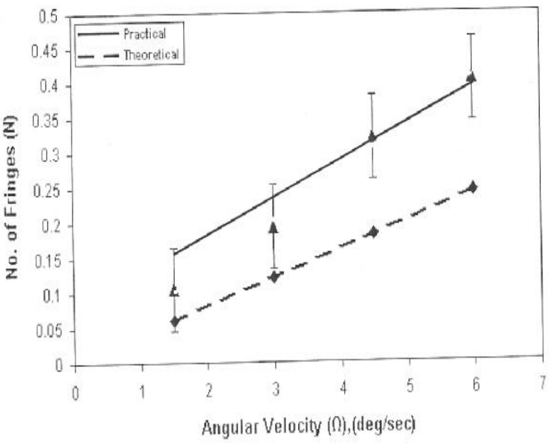

Fig.(13) Variation of number of fringes with difference angular velocities for length of optical fiber (L=12.8m) and diameter of turn (D=0.6m).

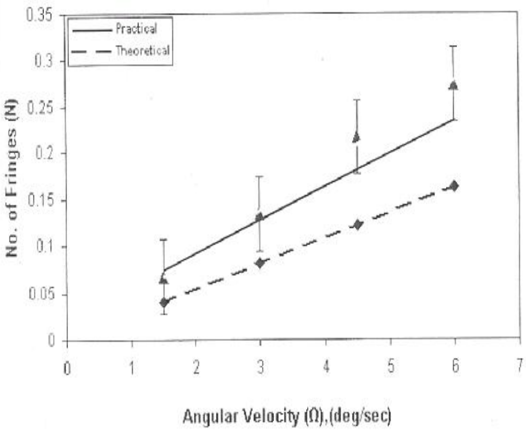

Fig.(14) Variation of number of fringes with difference angular velocities for length of optical fiber (L=12.8m) and diameter of turn (D=0.4m).

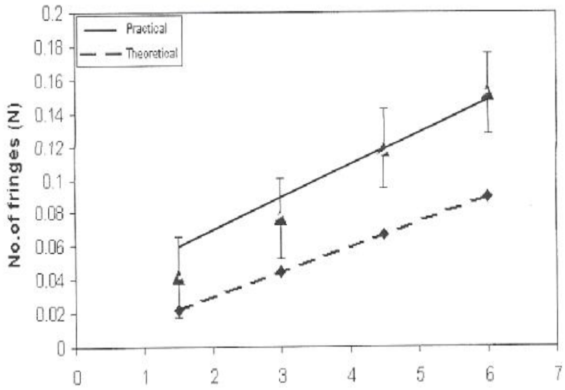

Fig.(15) Variation of number of fringes with difference angular velocities for length of optical fiber (L=12.8m) and diameter of turn (D=0.22m).

The Variation in the No. of Fringes as a Function of Different Diameters

If the angular velocity (Ω) is fixed, variation in the number of fringes (N) as a function of the change in the diameter (D) are plotted in Figs.(16, 17, 18 &19). The fixed angular velocities in these figures are respectively (1.5º/sec, 3º/sec, 4.5º/sec, and 6º/sec). Theoretical line was calculated from equation 8 in which

N= Constant * D

The constant= $\frac{L\Omega}{lc}$

The increase in the length of the optical fiber produces an increase in the number of fringes as given in equation 8.Here the value of the number of fringes of the same angular velocity and the same diameter of turn is increased with increasing the length of the optical fiber.

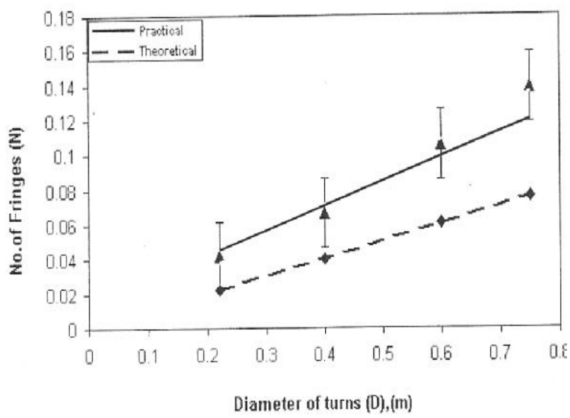

Fig.(16) Variation of number of fringes with diameter of turns of optical fiber for angular velocity (Ω=1.5 deg/sec) and length of fiber (L=12.8m).

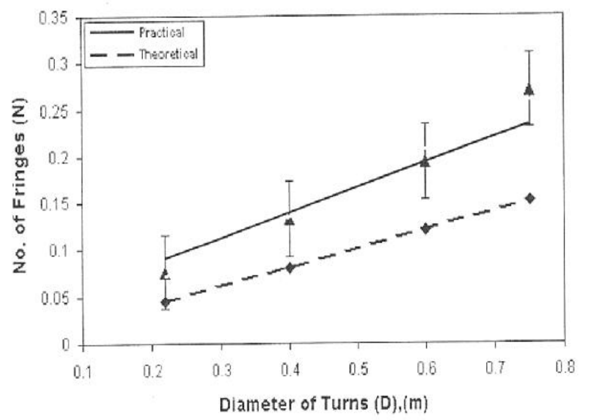

Fig.(17) Variation of number of fringes with diamrter of turns of optical fiber for angular velocity (Ω=3 deg/sec) and length of fiber (L=12.8m).

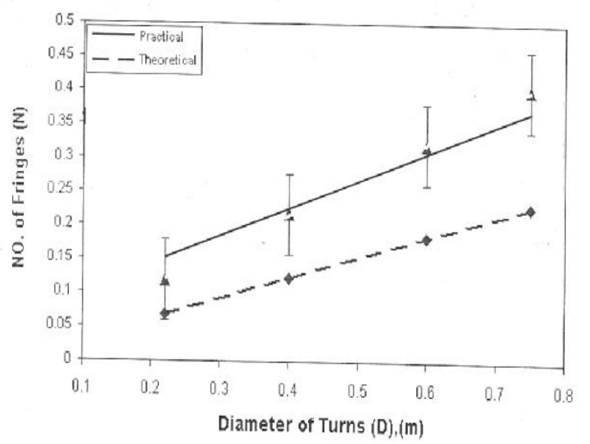

Fig.(18) Variation of number of fringes with diameter of turns of optical fiber for angular velocity (Ω=4.5 deg/sec) and length of fiber(L=12.8m).

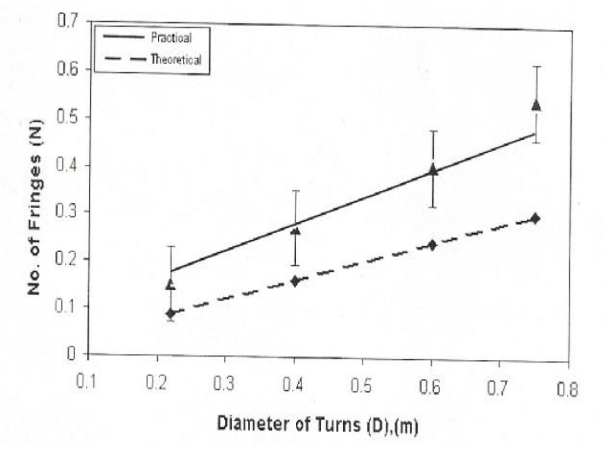

Fig.(19) Variation of number of fringes with diameter of turns of optical fiber for angular velocity (Ω=6 deg/sec) and length of fiber(L=12.8m).

Conclusion

The present research figures out the following:

1. Each of diameter of turns, angular velocity and, length of the fiber proportionate directly with the number of fringes, but the length of optical fiber is the more sensitive factor among others factors against the number of fringes.
2. The error ratio between the practical and the theoretical results in this study infers a direct proportionality with each of the angular velocity, length of optical fiber and diameter of turns.

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الخلاصة

تم دراسة تا ثير الدوران حسب مبدأ (Sagnac) على نمط التداخل الناتج من استخدام مقياس (Mach-Zehnder) للتداخل.

ان نمط التداخل ناتج من تراكب حزمتين ليزريتين ناتجتين من انقسام الحزمة الاصلية ومرور كل قسم في احد اذرع المقياس والذي هو عبارة عن ليف بصري لف بشكل دائري وتنتقل كل حزمة باتجاه يعاكس انتقا ل الحز مة الاخرى عند دوران المنظومة. يتولد اختلاف في زمن الانتقال بين الحزمتين المتعاكستين وبالتالي ينتج فرق مسار بصري يؤدي الى ازاحة الاهداب في نمط التداخل المتكون.

تم دراسة تاثير السرع الدورانية التالية (1.5درجة/ثا، 3 درجة/ثا، 4.5 درجة/ثا، 6 درجة/ثا) على عدد الاهداب المزاحة؛ حيث وجد انه يزداد عدد الاهداب المزاحة بزيادة السرعة الدورانية. ولقد تم ايضا دراسة تاثير اختلاف طول الليف البصري (2.8م ،12.8م) وقطر لفة الذراع لمقياس التداخل (0.22م،0.4م،0.6م،0.75م) على عدد الاهداب المزاحة، وقد وجد انه عدد الاهداب المزاحة يزداد بزيادة كل من الطول والقطر.