Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

MODELLING OF EXTRINSIC FIBER OPTIC SAGNAC ULTRASOUND INTERFEROMETER USED FOR DISPLACEMENT MEASUREMENTS

S. Benhamida* and F. Rehouma

University center of El Oued

Received: 25 November 2012 / Accepted: 02 December 2012 / Published online: 30 June 2012

ABSTRACT

Ultrasonic waves are used extensively in nondestructive testing both for characterization of material properties, in this paper, we describe a fiber optic sensor suitable for detection of ultrasonic waves. This sensor is based on an extrinsic fiber optic sagnac interferometer. The proposed sensor model can act as a conventional in-phase detector or as a narrowband detector. In this study we use methods interference of ultrasonic waves between the source of ultrasonic waves and the object under investigation is exploited. The main advantages of the proposed sensor are the ability to detect ultrasonic waves on the surface; this sensor possesses higher sensitivity and accuracy than the pulse method. The cavity resonator was very successfully used for measurement of small ultrasound velocity changes. The ultrasonic interferometric technique based on phase-locked loop is the most suitable for measurements of small displacements. This method ensures the highest sensitivity and accuracy.

Key words: Laser-based ultrasonic, fiber optic sensor, Sagnac interferometer.

1. INTRODUCTION

The Sagnac interferometer was first demonstrated by Monsieur Sagnac in 1913 [1]. The basic idea is very simple and it was a great tribute to Monsieur Sagnac's experimental ingenuity that he managed to make it work at the time. Figure 1 shows the principle.

Author Correspondence, e-mail: benhamidas9@gmail.com

ICID: 1017218

Light from an optical source is injected through a beam splitter such that it traverses in two directions around a loop. If that loop is rotated then light propagating in the same direction as the rotation has to ‘chase’ the beam splitter whereas that opposing the rotation finds the beam splitter advancing towards it. Consequently, the two directions within the rotating loop see slightly different optical paths. This. Difference is detected using optical Interferometry. Sagnac’s original experiment used a loop about 1m square and detected fringes when the loop rotated at a few times a second.

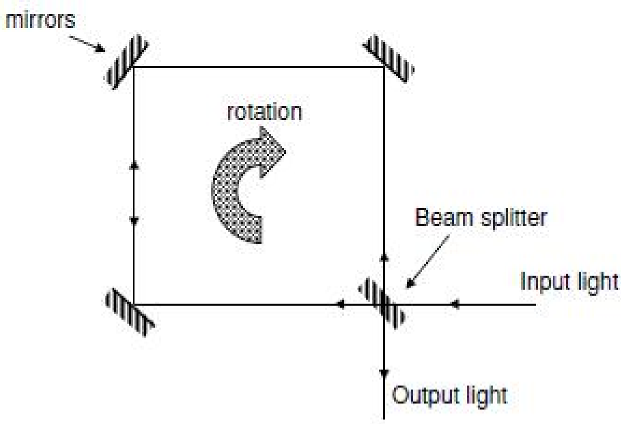

Fig.1. The sagnac effect in air: the clockwise path sees the beam

Sagnac interferometer

The optical fibre Sagnac interferometer was first demonstrated over 25 years ago. Immediately its potential for gyroscopic measurements became apparent and since the first demonstration substantial research and development investment has evolved a diversity of rotation measuring instruments. The fibre Sagnac interferometer has, however, also ventured into unexpected domains. The fibre loop mirror has become the ubiquitous reflector. Sagnac-based intruder alarms, hydrophones, geophones and current measuring systems have emerged. The Sagnac interferometer has expanded from the rotation measuring instrument into a very versatile sensing tool. Indeed, it is arguably the most successful of optical fibre sensing technologies. In this paper, we review both the principles and applications of the fibre Sagnac interferometer. The background theory highlights the need to understand the conditions for reciprocity within the interferometer network. The applications range from the expected gyroscopes into novel hydrophone arrays and intruder detection systems.

The basic interferometer is now well understood and the engineering required to realize useful and effective instruments has been carefully defined. Its versatility though continues to amaze even the most experienced

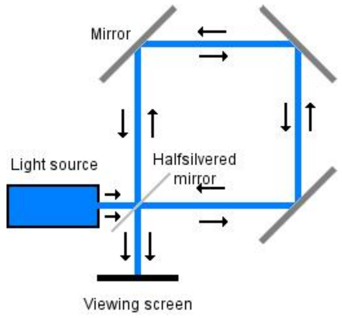

Fig.2. Schematic representation of a Sagnac interferometer

Usually several mirrors are used, so that the light beams follow a triangular or square trajectory. Fiber optics can also be employed to guide the light. The ring interferometer is located on a platform that can rotate. When the platform is rotating the lines of the interference pattern are displaced sideways as compared to the position of the interference pattern when the platform is not rotating. The amount of displacement is proportional to the angular velocity of the rotating platform. The axis of rotation does not have to be inside the enclosed area.

Fibre optic Sagnac interferometers: the basics

It is straightforward to deduce from figure 1 the phase difference between the two directions of propagation in the Sagnac interferometer in which the light travels in air (or more strictly vacuum). If the time taken for the light to traverse the loop path is Δt then within that time the beam splitter travels a distance Δx:

$$\Delta x = \Omega R \Delta t \quad (1)$$

Where R is the radius of the circle which forms the loop and Ω is the rotation rate in radians per second.

The actual path difference is twice this amount so with a little manipulation we find that the phase difference φ between the two beams is:

$$¤ = \frac{8®A\Omega}{a_0 c} \tag{2}$$

where A is the area enclosed by the loop (which can now be of any arbitrary shape without affecting the generality of the expression).

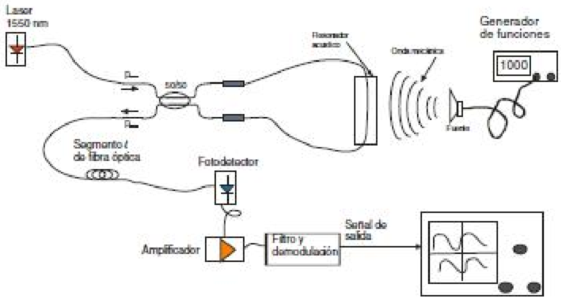

Fig.3. Setup of fiber Sagnac interferometer and ultrasound generation

Of course, this strictly speaking applies only to the case of the transmission of light around the loop in vacuum. If we replace the vacuum path with the optical fiber as indicated in figure 3 then we slightly modify the velocities of light in each direction to

$$c_{\pm} = \frac{c}{n} \pm \Omega R \sim \tag{3}$$

Where the suffix '+' applies to propagation with the direction of rotation and α is the relativistic drag imposed by the dielectric medium given as $\alpha = 1 - (1/n2)$ with n being the effective index of the fiber forming the loop. Interestingly, if we substitute the delays as a function of velocities as before, we still end up with exactly the same expression for the phase delay in terms of rotation rate as that given in equation (2) [9].

2. RESULT OF SIMULATION

Figure 4 shows this dependence for typical gyroscope after simulation of dimensions normalized in terms of L, the length of the fiber and R, the radius of the loop around which the fiber is wound. The principal features of this graph are that for rotation rates of navigational significance (around 10^{-2} deg per hour) sub micro radian phase shifts are to be expected. Consequently, the paths must be exactly balanced in the two directions. As we have already mentioned, effects other than Sagnac rotation induced phase can in fact produce significant path differences.

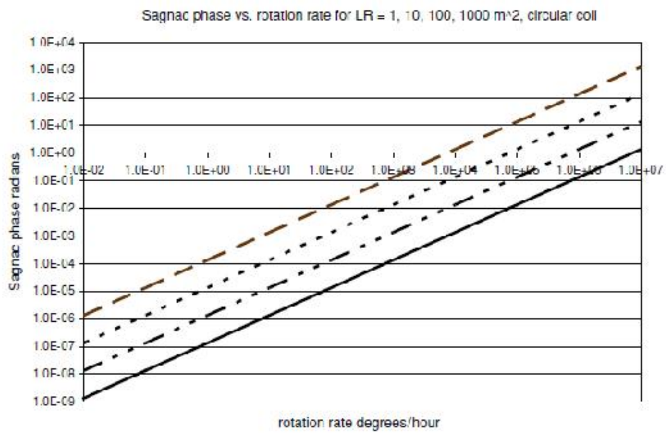

Fig.4. Phase difference due to rotation in a fibre Sagnac interferometer

The Fig. 5 shows the superposition of theoretical and experimental response comparison, evaluated in the range from 100 Hz to 20 kHz. Theoretical spectral gain is reached considering a photo detector Gaussian bandwidth of 13 kHz, and planar amplifier bandwidth of 20 kHz. We are considering that extinction ratio of resonant modes intensity are slower than the filter response of photodetector and amplifier. Separation modes were calculated for 2.5 *kHz.*

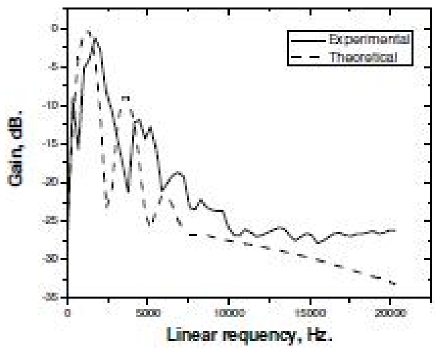

Fig.5. Response spectrums of acousto-optic detection

3. CONCLUSION

In this research we demonstrated the possibility of high birefringence optical fiber interferometer Sagnac can work as a linear laser modulator acousto-optic for frequencies from 20Hz to 20 kHz, in the region of 1550nm. We realized linear modulation for the intensity of a laser beam of 1550 nm at 21°C. As resonant system, it shows a gain spectrum distributed in discrete adjacent lobes, which correspond to a response of low pass filter. Acousto-optic modulator presents a linear spectrum phase in the range from 100 Hz up to 10 kHz. This demonstrates that the optical fiber acousto-optic modulator is capable of reproducing with enough intensity the frequencies that are contained in these lobes of the gain spectrum in dB.

4. REFERENCES

[1] Sagnac G. L'éther lumineux démontré par l'effet du vent relatif d'éther dans un interféromètre en rotation uniforme C. R. Acad. Sci, Paris. 1913, 95**,** 708-10.

Sagnac G. Sur la prévue de la réalité de l'´ether lumineux par l'expérience de l'interférographe tournant C. R. Acad. Sci, Paris. 1913, 95, 1410-3.

[2] Titterton D. H and Weston J. L. 1997, Strapdown InertialTechnology, Peter Peregrinus, Stevenage.

[3] Rosenthal A. H. Regenerative circulatory multiple beam interferometry for the study of light propagation effects. J. Opt. Soc. Am. 1962, 52, 1143.

Macek W. M and Davis D. T. M. J. Rotation rate sensing with travelling-wave ring lasers Appl. Phys. Lett. 1963, 2**,** 67-8.

[4] Aronowitz F. 1971, The laser gyro Laser Application. vol 1, ed M M Ross, New York: Academic.

[5] Vali V and Shorthill R. W. Fiber ring interferometer. Appl. Opt. 1976, 15**,** 1099-100.

[6] Lefèvre H. C. 1993, The Fiber Optic Gyroscope, Norwood, MA: Artech House, p 313.

How to cite this article
Benhamida S and Rehouma F. Modelling of extrinsic fiber optic Signac ultrasound interferometer used for displacement measurements. J Fundam Appl Sci. 2012, 4(1), 11-16.