Analyzing Characteristics of Sagnac Loop Interferometric Stress Sensor

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***Abstract*-- Effect of transverse induced stress on fiber optic Sagnac interferometer has been studied. The Sagnac loop is designed with conventional single mode fiber. Applying transverse stress on the fiber loop, resulting interference patterns are captured by a CCD and hence analyzed to obtain the angular shift of deformations by image processing technique using MATLAB. Data are taken from the single and double fiber optic loops of the Sagnac interferometric configurations and hence a comparative study is performed to achieve better sensitivity.**

Key words—Fiber optic interferometer, Sagnac configuration, Stress sensor, Image processing

I. INTRODUCTION

Interferometer based fiber optic sensors gains a promising position in the photonics sensor industry due to their phase sensitive characteristics which results higher resolution and higher sensitivity compare to conventional intensity based sensors. For measuring widely varied physical, chemical or Bio parameters in harsh environment, various types of fiber optic interferometric sensors have been reported so far [1-4].These interferometric set-ups are easy to design though achieve a potential performance. For example, a Sagnac interferometric set-up can be designed in such a simple way by making a loop with conventional single mode fiber(SMF). It can be explored as an interferometric sensor where the phase relation deals with the very acute intrinsic birefringence of fiber due to geometrical asymmetry of core. Thus a fiber optic Sagnac interferometer achieves relatively high sensitivity in response to temperature and strain [5]. However these sensors are less devoted for acoustic and strain sensing. In the fields of acoustic sensing [6-8] the Sagnac fiber optic interferometers used for position sensitive sensing, distributed sensing and filtering of low frequency signals [9-10]. Sagnac interferometers mainly adapted for rotational sensing applications have drawn a new attention for navigational and guiding applications. Such a rotational behavior can be directly explored by observing the continuous periodic changes of the resulting interferometric patterns. Keeping this in mind, in this article we have analyzed the image response of a Sagnac loop interferometric patterns by applying transverse stress on the loop. We have set up simple stress induced Sagnac loop with a conventional single mode fiber (SMF). Increasing the stress in form of loading weights on fiber loop, the resulting output fringe patterns of interferometer are captured using CCD camera. The captured images are analyzed using image processing technique with MATLAB by measuring the angular shift of the deformation.

II. THEORY

In fiber optic Sagnac interferometer, the incident light passing through coupler is divided into two parts: one propagates in clock wise direction and the other propagates in counter-clock wise direction. These two counter propagated light beams recombined by the coupler and thereby results in an interference pattern which can be detected at the output end of the Sagnac loop. However, the Sagnac fiber optic loop made with conventional SMF, deals with the phase parameter of orthogonal modes (HE_{11}^{x} and HE_{11}^{y}) which are excited due to intrinsic geometrical asymmetry. These two modes propagating with different phase velocities in apparently single mode fiber result an intrinsic birefringence [11-14].

In addition to these intrinsic effects, birefringence can also be induced in an optical fiber by external stress, produce an optical anisotropy which is known as Opto-elastic effect [15-16]. Therefore, due to this stress induced birefringence effect, the phase difference introduced between the orthogonal modes can be expressed as [17]

$$\Delta\emptyset = \frac{4\eta^3}{2RE\lambda}(P_{12} - P_{11})(1 + \mu)LP \qquad (2)$$

Where P_{12} and P_{11} are the components of the strain optic tensors of the fiber, λ is operating wavelength, η is effective reflective index of the fiber, μ is the Poisson ratio, R is the radius of the fiber, E is the young's modulus, L is the fiber length under stress within the loop and P is the applied pressure (stress through the known weight). It can be observed from equation (1) that the phase difference has a linear relationship with the transverse stress. Now applying these stresses, the induced birefringence (i.e. phase difference) interacts with the initial phase difference due to intrinsic

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birefringence. As a result, it comes up with a periodic response sometimes cancelling each other or sometimes adding in same way. While applying the weights the induced birefringence effect allows sensing the physical parameters such as stress, temperature, pressure, elongation, etc. [18-22].

III. EXPERIMENTAL SETUP

The Physical layout of the experimental setup is depicted in the Fig. 1. Mainly, it consists of He-Ne laser at 632.8 nm, a 3dB 2x2 optical coupler, CCD Camera (Thorlabs,

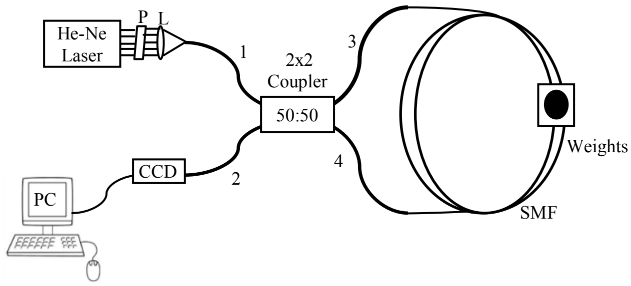

Fig.1 Experimental set up of the Fiber optic Sagnac Interferometer.

DCU 223C), single mode fiber (SMF) having core/clad diameters 9/125 µm respectively.

A Sagnac fiber optic interferometer is designed by splicing a convention SMF between port-3 and port-4 of the 2x2coupler. Hence it forms a fiber loop desired for Sagnac configuration.

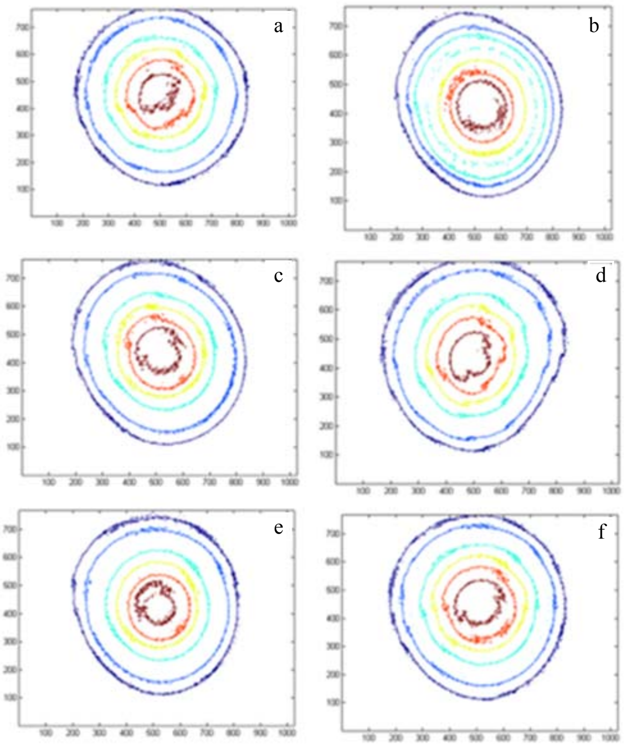

Fig. 2. Contour plots of the fringe patterns corresponding to change in applied weights on a single loop configuration a) 0 kg b) 0.3 kg c) 0.5 kg d) 0.9 kg e) 1.5kg f) 1.7 kg respectively.

The port-1 is used for launching the light into the Sagnac loop and the port-2 is connected to CCD camera. Initially, the light from He-Ne laser is polarized by a polarizer (P) and then is coupled into the Sagnac loop by using a eyepiece lens *L*. Single mode fiber that is spliced between port 3 and port 4 of the coupler which is arranged to form two loops. The SMF loop is placed on perfectly plane surface and a thin smooth steel plate of negligible weight is kept on it as shown in Fig. 1. The applied weights on the fiber loop are increased in steps of each 0.1 kg up to a dynamic range of 4 kg. The output beam profiles corresponding to the applied weights are captured by CCD Camera and recorded into a PC.

IV. RESULTS AND DISCUSSION

The experiment is performed in two steps; Firstly with single loop SMF configuration and secondly with double loop SMF configuration.

A. Single loop SMF configuration

Using a single Sagnac loop, we have started with weight of 0.1 kg. It will produce the stress induced birefringence which results the deformation of circular interference pattern. From the captured images of interference fringe patterns for varying

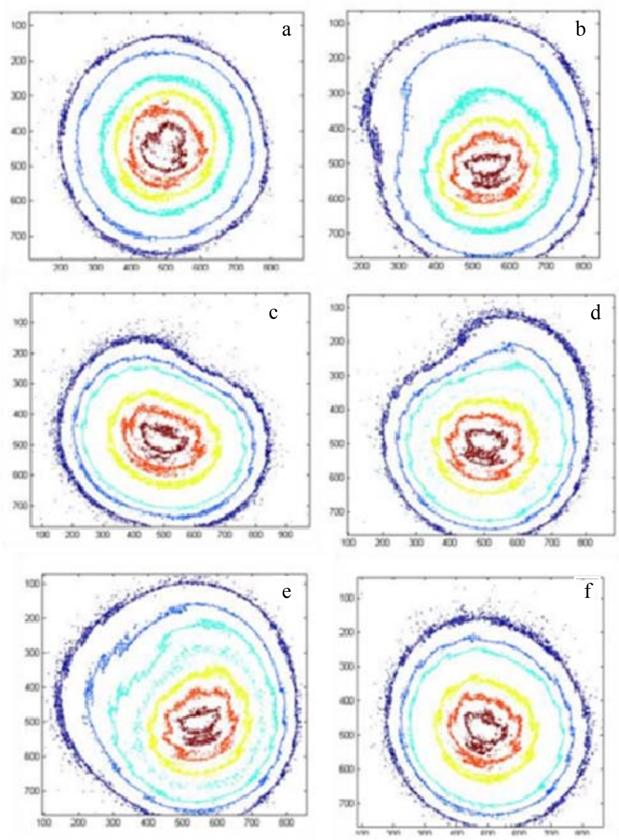

Fig. 3. Contour plots of the fringe patterns corresponding to change in applied weights on a double loop configuration a) 0 kg b) 0.3 kg c) 0.5 kg d) 0.9kg e) 1.5kg f)2kgspectively.

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weights, the contour plots (shown in Fig. 2) are extracted using MATLAB. It is clear to notice that with increasing weights, the shapes of non-circular fringe patterns are found to be deforming and rotating with a repeated way. Eventually it records a phase response which is measured by the angular shift of a particular point of respective contour plots.

B. Double loop SMF configuration

To achieve better sensitivity, the experiment is repeated similarly by double loop of fiber with same radius. Applying steps of weights, the obtained fringe pattern contours are presented in Fig. 3. Here we also achieve same repetitive nature of pattern with respect to increasing load.

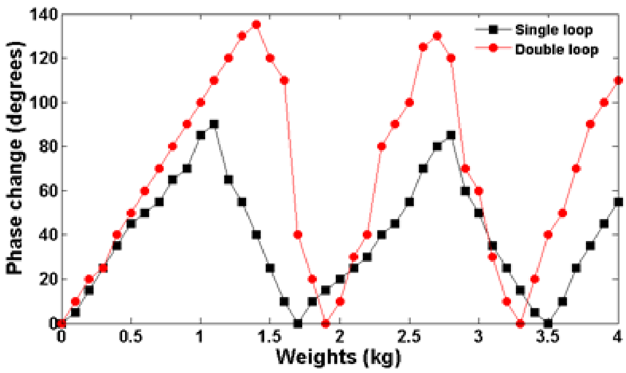

Fig.4.Comparison between single loop and double loop configurations for angular shift in fringe patterns with respect to applied weights.

The images are analyzed by measuring the angular shift of a particular point of a contour. The measured angular shifts with respect to weights are plotted in the Fig. 4 for the both configurations. In comparison to single loop configuration, it is observed that double loop configuration exhibits more deformation in beam profile and exhibits a large linear dynamic range for applied weights. Altogether it clearly carries the signature of changing phase in the Sagnac loop due to induced birefringence. Such periodic shift of fringe patterns also justifies the periodic intensity variation of the output [23].

V. CONCLUSION

A simple image processing technique to study the effect of transverse induced stress on a Sagnac interferometer made with conventional SMF fiber loop has been reported. The deformed fringe patterns due to increasing weights are captured by a CCD camera and hence analyzed by MATLAB to obtain the angular shift of deformation. A comparative study has been done between single and double loop configurations corresponding to the change in applied weights results angular deformation of the fringe patterns. In comparison, the double loop configuration exhibits more deformation in rotational state of beam profile and also shows large linear dynamic range.

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REFERENCES

[1] Qingxu YU and xinlei ZHOU "Pressure Sensor Based on the Fiber-Optic extrinsic Fabry-Perot Interferometer", Photonic Sensors(2011) Vol.1,No. 1:72-83
[2] Cheng Ma and Anbo Wang "Signal processing of white light inter-ferometeric fiber-optic Fabry-Perot sensors", Applied Optics(2013), vol.52 ,No.2.
[3] Kenji Wada,Hirokazu Narui,Daiki Yamamoto,Tetsuya Matsuyama and Hiromichi Horinaka "Balanced polarization maintaining fiber Sagnac interferometer vibration sensor",Optics Express(2011),vol.19,No.22
[4] Horacio Lamela,Daniel Gallego,Rebeca Guitierrez, and Oraevsky,"Interferometric fiber optic sensors for biomedical applications of optoacoustic imaging",Journal of Biophotonics 4,No.3,184-192(2011).
[5] X.Dong, H.Y.Tam, and P.Shum, "Temperature-insensitive strain sensor with polarization maintaining photonic crystal based Sagnac interferometer," Appl.Phys.Lett. 90, 1511-1513, 2007.
[6] K.Krakenese and K.Blotekjaer, "Sagnac interferometers for under water sound detection: Noise Properties," Optics Letters, Vol.14, P.1152, 1989.
[7] E.udd, "Fiber optic Acoustic sensor Based on the Sagnac Interferometer" Proceedings of SPIE, vol.425, p.90, 1983.
[8] J.T.Kringlebotn, K.Blotekjaer and C.N.Pannell, "Sagnac Interferometer including a recalculating Ring with an Erbium Doped Fiber Amplifier", Proceedings of the 8th Optical Fiber Sensors Conference, p.6, Monterey, 1992.
[9] J.Dakin, D.A.Pearce, A.P.Strong, and C.A.Wade, "A novel Distributed optical fiber sensing system Enabling Location of Disturbances in a Sagnac Loop Interferometer," Proceedings of SPIE, vol.838, p.325, 1987.
[10] E.Udd, "Sagnac Distributed sensor Concepts", Proceedings of SPIE, vol.1586, p.46, 1991.
[11] D.Lee, Electromagnetic Principal of Integrated Optics,John Wiley &Sons, New York,1986.
[12] G.Elinarsson, Principals of Light wave Communications, John Wiley & Sons, Chichestor, 1996.
[13] John M.Senior, Optical Fiber Communications: Principal and Practice, Pearson ,*ISBN 978-81-317-3266-3,2010.pp.141.*
[14] L.P.Kaminow, "Polarization in Optical fibers," IEEE J.Quant.El., vol.17.no.1.pp.15-22.Jan.1981.
[15] J.Tsuji, M.Nishida, and K.Kawada, "Experimental methods of photo elasticity," Nikkan Kogyo-sha (in Japanese), 1975.
[16] Y.Namihira,M.Kudo, and Y.Mushiake, "Effect of mechanical stress on the transmission characteristics of optical fibers," Trans.Inst.Electron.Commun.Eng.Japan,vol.60-C,pp.391-398,1977.
[17] J.Gan, L.Shen, Q.Ye, Z.Pan, H.Cai, and R.Qu, "Orientation-free pressure sensor based on π-shifted single –mode-fiber Sagnac interferometer," Appl.Opt.**49**,5043-5048,2010.
[18] O.Frazao, J.M.Baptista, and J.L.Santos, "Recent advances in high birefringence fiber loop mirror sensors," Sensors **7**,2090-2983,2007.
[19] K.S.Lim,C.H.Pua, and N.A.awang, "Fiber loop mirror filter with two stage high birefringence fibers, "Prog.Elctromagn.Res.C **9**,101-108,2009**.**
[20] T.A.Birkis and P.Morkel, "Jones calculus of single-mode fiber Sagnac reflector," Appl.Opt. 27, 3107-3113,1988.
[21] F.Liu, Q.Ye, F.Pang, J.Geng,R.Qu, and Z.Feng, " Polarization analysis and experimental implementation of PLZT electro-optical switch using fiber Sagnac interferometeres," J.Opt.Soc.Am.B **23**,709-713,2006.
[22] X.Fang and R.O.Claus, "Polarization-independent all fiber wavelength division multiplexer based on Sagnac interferometer," Opt.Lett.**20**, 2146, 2418, 1995.
[23] Saba N. Khan, Sudip Kr. Chatterjee, Kajal Modal, and Partha Roy Chaudhuri , "Characteristics of transverse-stress-induced phase change through a distinct dual-mode fiber in a Sagnac loop," J.Opt.Soc.Am.A,vol.30,no.5,May2013.

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