Application principle of Sagnac interferometer in optical fiber gyroscopic system

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***Abstract* — Gyroscopes are widely used in various applications for decades, but the idea to construct a gyroscopic system, able to exploit the properties of the gyroscope and also monitor the status information arose later. The expansion of the optical fiber technology also touch the subject, with the development of such interferometer measuring means to explore a variety of non-optical parameters led to the idea of the application of this knowledge to the already known systems. This optical system has been constructed on a fundamental principle of the gyroscope, but we can't talk about pure gyroscope, because there is an optical interferometer that uses its features. So it was named as fiber optic gyroscopes. In this article we describe fiber optic gyro system, design and testing experimental measurements with this gyroscope system.**

Keywords—Optical fiber gyro system, OTDR, Sagnac effect

I. Introduction

There are four known types of interferometer: Michelson, Mach-Zehnder, Fabry-Perot and Sagnac. They are based on propagation of light in the two arms. First arm is used as reference and second one is used as measured fiber. Using these interferometers in various applications can also examine non-optical parameters. One of interferometer types with a single optical fiber is optical fiber gyro system based on the principle of Sagnac interferometer. The design of the sensor is fully optical with using single mode fiber type G-625-D. Tested wavelength is selected according to the type of used laser, the most frequently used 1310 and 1550nm. The principle of the fiber optic gyroscopes is based on the spread of the two light beams directed in optical fiber, which is due to greater efficiency gyroscopic module wound into a coil shape. These light beams have been propagated towards each other so first beam is directed clockwise and the second beam is directed counterclockwise. The optical fiber with mentioned beams is being rotated. Detector is able to examine speed and the direction of the optical fiber gyroscopic module [1-3].

II. Optical fiber gyroscope

The basis for optical fiber gyro system is a Sagnac interferometer using which it is possible to examine the above-mentioned properties. This model describes the differential phase shift caused by the Sagnac effect which occurs between the optical signal interference in clockwise (CW) direction and optical signal spread in counter-clockwise (CCW) direction in optical fiber wound into a coil. Sagnac effect is a phenomenon in the interferometer, which in this case occurs at the circular rotation of the optical fiber wound into a coil shape. The light beam is split into two light beams that propagate in opposite directions in enclosed area and interference is caused by recombination of individual beams. The entire process takes place in an optical fiber, which is used both as a transmission medium, but also as a component in which Sagnac effect occurs.

The phase difference depends on the constant representing Sagnac effect φ_S, which is proportional to the scalar product of the vector speed rotation $\vec{\Omega}$ and vector space $\vec{A}$ through bounded route:

$$\varphi_S = \frac{4\omega}{c^2}\vec{A}\cdot\vec{\Omega} \qquad (1)$$

where ω is the angular frequency of the light source and c is the speed of light[4-7].

It is possible to increase sensitivity of coil by increasing the speed of rotation. Higher speed also positively affects the area covered by vector $\vec{A}$. Efficiency of Sagnac effect can then be expressed by equation:

$$\varphi_S = \frac{2\pi}{\lambda}\frac{LD}{c}\Omega_{II} \qquad (2)$$

where L is the total length of the optical fiber, D is the diameter of the coil, which is wound into the optical fiber, λ is the wavelength of light emitter from the source and Ω_{II} the speed of rotation parallel to the axis of rotation[4-7].

III. Experimental measurements of the optical fiber gyro system

The objective of these measurements is analysis of the results obtained with experimental measurements with optical fiber gyro system. The progress of the measurement consists of several parts. The first part is the use of OTDR (Optical Time Domain Reflectometer) to test and measure the length of the optical fiber, as this value is crucial for the calculations required for the next part of measurements. This technology allows determination of the inhomogeneity of optical fiber coil used in a gyro module. The next step is to test the gyroscopic module without connecting low-frequency generator that modulates the signal distributed in the fiber. This measurement is used to verify the functionality of gyroscopic module to the subsequent measurements it is possible to determine the final character of signal obtained at the detector elements. The final measurement is complete integration of all necessary components of the assembly and it is configured according to values obtained in previous measurements [8-10].

A. Testing fiber optic gyro model using OTDR technology

OTDR is based on the principle of transmission of the short optical impulses into the optical fiber. Spread of narrow optical impulse in optical path is evaluated as key parameter for time dependency of backscattered optical power. This allows to detect the location of optical fiber dispersion. OTDR uses two types of phenomena: Rayleigh dispersion and Fresnel reflection. OTDR dead zone and its origin are defined in the reflection from inhomogeneity in the transmission path. Detector saturation occurs and this causes the back-reflected light. Saturation causes partial decommissioning of detector when the detector is not able to detect other inhomogeneity located on transmission path. Creation of large dead zone can be prevented by attaching additional optical fiber, which would increase stability of OTDR measurement. The measurements were made at two wavelengths. First wavelength is 1310nm (Fig. 1) and second is 1550nm (Fig. 2). Usable length of optical fiber wound into a coil is 5263.6m. Attenuation is evenly distributed in the optical fiber wound into a coil shape. The greatest attenuation occurs in the zone that is associated with terminating fiber. In the following measurements, the selected wavelength is 1550nm [1, 10].

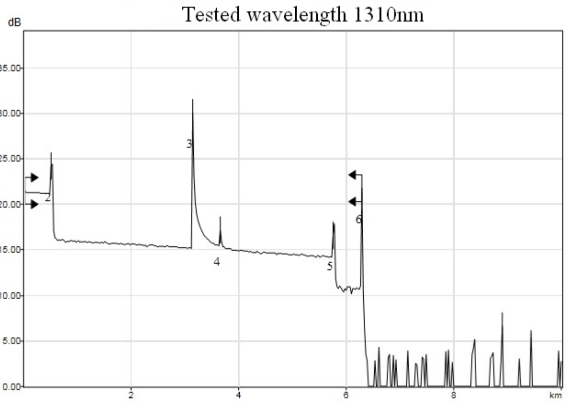

Fig. 1 Result testing fiber optic OTDR method at a wavelength of 1310nm

B. Functional testing of gyroscopic module - measurement without using phase modulation

This measurement involves the elements of Fig. 3, which contains the following components: optical laser, optical isolator, coupler, gyroscope module, detector and oscilloscope.

The components necessary to the realization of the measurement on Fig. 3 are: optical laser (ASE laser – Amplified Spontaneous Emission laser) with optical output power 20 mW, the energizing current 80 mA, operating at a wavelength of 1550 nm, optical isolator to protect against rays backscattered towards the source of emission, a detector converting the optical signal to allow the power that can be displayed on the output device monitoring in this case of an oscilloscope. Type of used detector is InGaAs photodiode with sensitivity 228mV/µW at wavelength 1550nm. The important component is optical splitter.

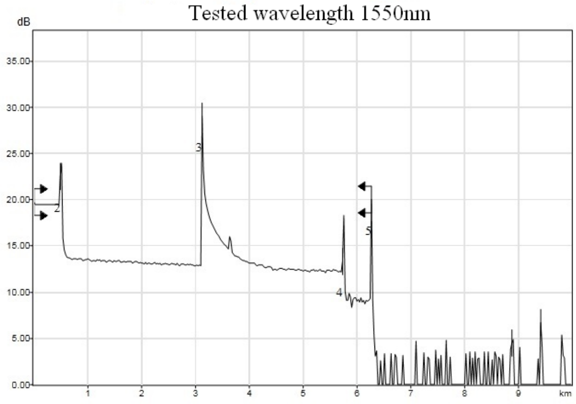

Fig. 2 Result testing fiber optic OTDR method at a wavelength of 1550nm

Optical fiber gyro module contains the optical fiber with length of 5263.6m coiled into a coil with diameter 14cm and type of fiber is SMF28. This fiber is standard single mode fiber support for transmission of signals with a wavelength 1550nm. The type of the fiber has been selected based on the requirements for the Sagnac effect. The block of gyro module consists of polarizer and depolarizer. These elements modify charge polarization of the optical signal spread in optical fiber. Piezoelectric module controls the rotation of the optical fiber coil in which the optical signals propagate.

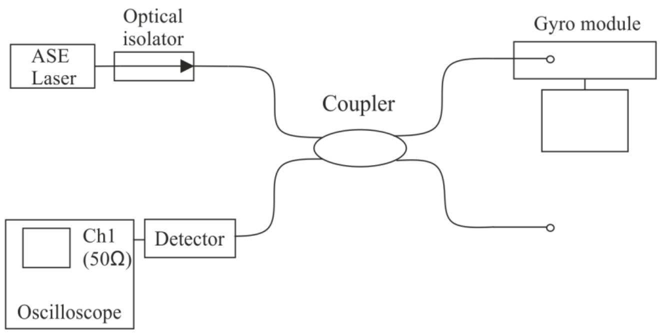

Fig. 3 Configuration of optic fiber gyroscope without phase modulation

The correct configuration and starting propagation signal can be determined by form of signal. This signal is not modulated therefore it has stochastic character, however by controlling of gyroscope module rotation the changes of signal character are visible [11-15].

IV. Experimental Measurement with Connecting the Modulator Signal

Schematic configuration of components used in the measurements is supplemented by a signal generator, which will modulate the signal. In Fig. 4 is represented by block GBF (fr. Generateur Basse Frequence). Correct configuration will provide the exact final values obtained at the output. From the final values obtained from oscilloscope is possible to determine direction of gyro module rotation. The exact final values are obtained from relation of signal on oscilloscope and reference signal obtained from signal generator. If signal on oscilloscope has the same phase delay as reference signal it is possible to say that gyro module is in clockwise rotation, while signal, which arrived as first was transmitted in clockwise direction and therefore it needs to travel the same distance, which is shorter than the distance of signal from opposite direction. Thus the direction of rotation can be determined by obtained phase differences of signals [11].

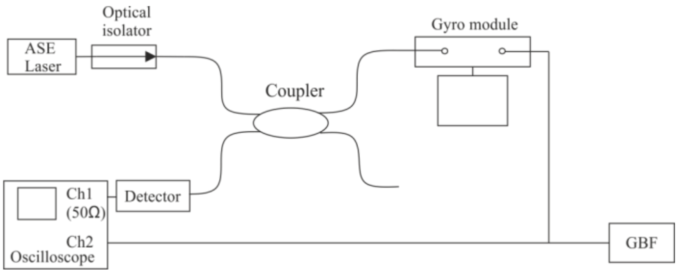

Fig. 4 Schematic optic gyroscope with signal generator

GBF represents signal generator. In this case is used low frequency generator from Rohde & Schwarz SML03 with frequency range from 9 kHz to 1.1 GHz, which meets the requirements for the measurement. Low frequency generator is connected with piezoelectric component placed in optical fiber gyro module and with one channel of oscilloscope, where this channel will serve as reference signal. We generate sinus signal with frequency f_m obtained by calculation and this signal is directed in piezoelectric element and into oscilloscope.

Frequency generated by sinus signal is obtained by calculation of equations (3, 4):

$$f_m = 1/(2\tau), \qquad (3)$$

$$\tau = L/v = n \cdot L/c, \qquad (4)$$

while L is total length of optical fiber wound into coil, n is a refractive index of the optical fiber, c is speed of light in vacuum.

Substituting each value for elements available in laboratory we get:

$$\tau = \frac{1{,}46 \cdot 5263{,}6}{3 \cdot 10^8} = 2{,}56162 \cdot 10^{-5}\, s, \qquad (5)$$

$$f_m = \frac{1}{2 \cdot 2{,}56162 \cdot 10^{-5}} = 19518{,}9084 Hz = 19{,}52 KHz. \qquad (6)$$

These values such as frequency obtained by calculation are configured on signal generator, while type of signal is sinus. By doing experimental measurements were obtained waveforms displayed on Fig. 5, Fig. 6. In these measurements the speed and direction of rotated module has to be changed. The most important factor is phase difference of examined and reference signal. Gyro module can choose available speed of rotation, therein emphasize the dependence accuracy determine the direction in relation into speed of rotation.

Signals which are propagated in counter-clockwise direction obtain phase difference through the creation of Sagnac effect, which occurs in the optical fiber. On Fig. 5 are displayed waveforms of signal rotated in counter-clockwise direction. Waveforms which represent signal rotated in clockwise direction are displayed on Fig. 6. Part A1 from Fig. 5 represents direction of counter-clockwise rotation at low speed. Part B1 from Fig. 6 represents direction of rotation clockwise at low speed.

The speed of rotation is changed toward the higher speed until it reaches a peak as seen on part A3 from Fig. 5 and also in the bottom right of the part B3 from Fig. 6. Oscillations are caused by imperfection of gyroscope module and its sensitivity to changes caused due mechanical interference. Used gyro modules are not prone to these problems and sensitivity to shocks or other factors that disrupt accurate measurement. Gyro module used in experimental measurement is sensitive to shocks and that is the reason for preventing their occurrence.

V. Conclusion

Optical fiber gyroscope system is specific system. This system is based on principle of Sagnac interferometer, due possible measurement of signal waveforms phase difference. This phase difference can be examined by experimental measurements made on measurement kit. This kit was also used for gaining knowledge about properties of proposed optical fiber gyroscopic system. The knowledge was then used at design stage of experimental measurements.

In this article we tried to point out dependence of accuracy and rotation direction by changes of speed and phase. These changes of signals were caused by Sagnac phenomena. Created phase changes can determine direction of gyro module rotation. This phenomenon could be better recorded at higher speeds of gyro module rotation. Hence waveforms of resulting signal could be considered as more precise. Results show phase change signal depends on the parameters as speed and rotation direction.

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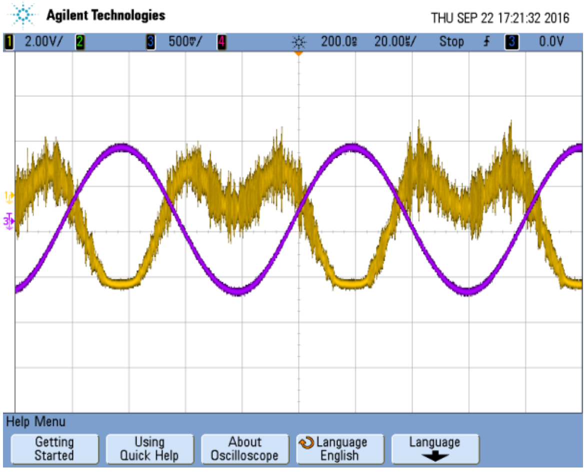
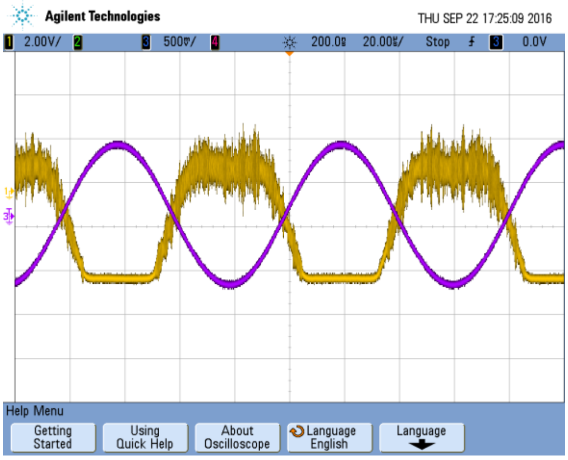
The output of the gyroscopic module having a counter-clockwise rotation



A 1

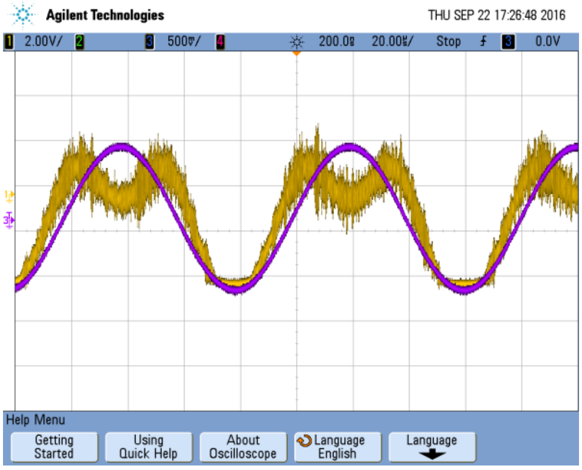
A 2



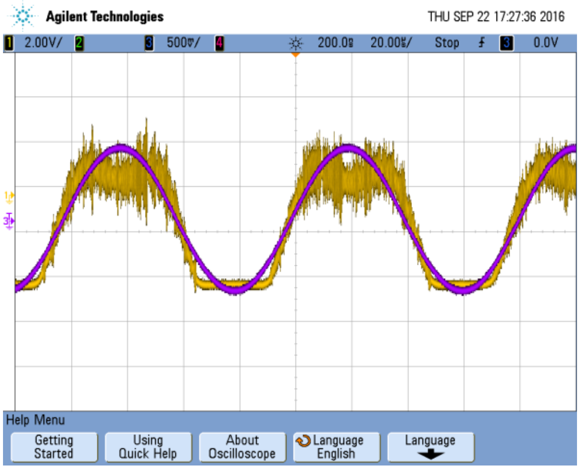
A 3

Fig. 5 Compare waveforms input signals at counter-clockwise rotation and different speed of rotation

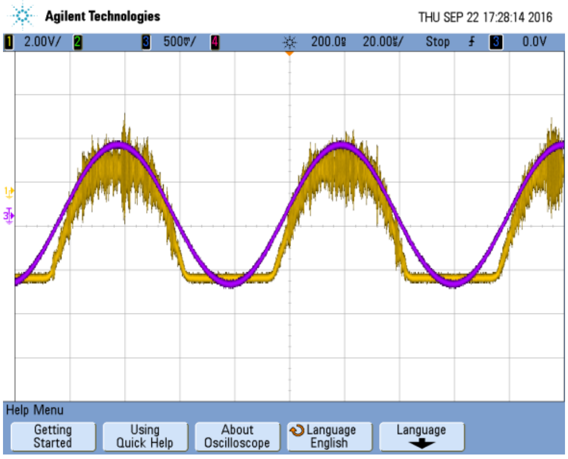
The output of the gyroscopic module having a clockwise rotation



B 1



B 2



B 3

Fig. 6 Compare waveforms input signals at clockwise rotation and different speed of rotation

VI. References

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VII. Biographies

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Ján TURÁN (Dr.h.c., prof., RNDr., Ing., DrSc.) received Ing. (MSc.) degree in physical engineering with honours from the Czech Technical University, Prague, Czech Republic, in 1974, and RNDr. (MSc.) degree in experimental physics with honours from Charles University, Prague, Czech Republic, in 1980. He received a CSc. (PhD.) and DrSc. degrees in radioelectronics from University of Technology, Košice, Slovakia, in 1983, and 1992, respectively. Since March 1979, he has been at the University of Technology, Košice as Professor for electronics and information technology. His research interests include digital signal processing and fiber optics, communication and sensing.

Michal Špes was born in 1991. In 2015 graduated (MSc) at the department of electric power engineering. At present is a Ph.D. student in the Department of Electric Power Engineering on the Faculty of Electrical Engineering and Informatics at Technical University in Košice. He received a master degree in electric power engineering on subject evaluation of generator exciting outage. His scientific research is mainly focused on research of powerline ampacity system.