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A high performance and low-cost polarimetric fiber-optic pressure sensor

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In this paper we present the working principle, fabrication and operation of a high performance, but low-cost, polarimetric pressure sensor using standard single-mode fibers. The measurement system exploits the coupling between the two orthogonally polarized fundamental modes in a standard fiber and is based on the direct evaluation of the power variation along a predefined linear polarization. The transducer is made by few loops of fiber sandwiched between two plates and its sensitivity can be tailored by changing the number of loops and position.

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1. Introduction

Over the last years several optical fiber sensors based on various physical principles (e.g. light amplitude, phase, frequency or polarization modulation), and for a wide range of applications, have been reported in the literature [1]-[5]. Optical fiber sensors offer numerous advantages over conventional sensing technologies such as high sensitivity, complete immunity to electromagnetic interference, very versatile range of measurand to lightwave transduction techniques and possibility to operate in harsh environments.

Among fiber sensors, polarimetric fiber sensors, as their name implies, measure the quantity of interest through the variation of the light polarization state in a single mode fiber (SMF) with external factors, like deformation induced stress and temperature. Most of the polarimetric fiber sensors presented so far in the literature are based on interferometric schemes making use of high-birefringent (HB) polarization maintaining (PM) fibers [5]-[7]. These are fibers typically employed with polarization-dependent devices to allow them to operate with a predefined polarization regardless of the environmental effects.

In this paper we report the experimental realization of a polarimetric pressure sensor that uses a standard SMF, like those widely deployed for data transmission, and thus that can be easily integrated into existing fiber networks. To keep the overall costs low, the measurement system is based on the direct evaluation of the power variation along a predefined linear polarization, without requiring complex interferometric setups.

2. Fabrication of the sensor, working principle and characterization

As well known, the polarization of an electromagnetic wave is related to the orientation of the electric field vector and it changes along the propagation path due to material anisotropy, reflections, scatterings, etc. Polarimetric sensors typically exploit the birefringence induced by the quantity of interest through micro-bending or other tensile/compressive strains or electro- or acousto-optic effects. In particular, it is then possible to fabricate a low-cost polarimetric fiber-optic pressure sensor exploiting the perturbation-induced coupling between the two quasi-degenerate orthogonally polarized modes of a single-mode fiber. This way the sensor may be essentially composed of a laser diode operating in CW mode, a mechanical polarization controller to allow selecting the working point in absence of the applied stimulus, an SMF span acting as the sensing part, a fiber pigtailed polarizer and an optical receiver that is connected to a PC via a digital acquisition card. The working principle is presented in more detail in ref. [2] and can be summarized as follows: the light emitted by the laser source feeds the pressure transducer via the mechanical polarization controller, which is typically used to align the incident polarization orthogonally to the transmission axis of the polarizer in absence of the applied pressure stimulus, so to read ideally zero at the receiver. When pressure acts on the transducer, the polarization state in the SMF is perturbed and the power transmitted through the fiber polarizer increases. Therefore, if an orthogonal input polarization has been selected in absence of perturbation, upon application of the pressure stimulus an optical power different from zero is obtained at the receiver. A similar situation, but with a reduction in the received power, occurs if a parallel input polarization has been chosen. The mechanical polarization controller we used allows selecting the polarization state entering the sensing region by adjusting the angles of three plates with fixed retardation and variable orientation angle. The receiver is made by a photodiode connected to a transimpedance amplifier, a filtering stage and another final amplifier. In our prototypes the data acquisition has been performed using a commercial 16-bit digital acquisition card controlled by a program developed using the language LabView from National Instruments.

The pressure transducer is typically made by few loops of fiber sandwiched between two plates [2], although different embodiments can be devised depending on the specific sensing requirements. Furthermore, the transfer function between the applied pressure and the polarization variation can be tailored by changing the number and position of the fiber loops and by adding shock absorbing layers if lower sensitivity and broader operation range are required.

Although the proposed sensor has been designed to measure abrupt variations of pressures, so in principle slow variations of polarizations could be neglected, prior to its usage in practical applications, a prototype has been fully characterized to asses the stability of the received polarization with time in absence of external stimuli. For this purpose, a power beam splitter has been inserted after the sensor (Fig.1) to allow comparing the readings from the receiver with those of an Agilent *8509C* Lightwave Polarization Analyzer. Various tests lasting few days each, with different laser diode input currents and different environmental temperatures, have been carried out to simulate different working conditions.

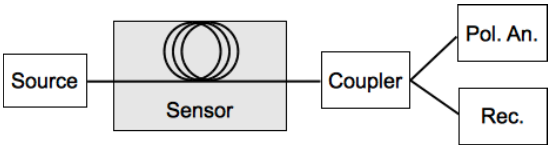


Fig. 1. Scheme of the measurement setup used to assess the stability of polarization with time in absence of applied stimuli to the sensor.

In all the considered cases an excellent stability of the output has been obtained, well within the requirements for the target applications. An example is shown in Fig. 2 and in Fig. 3, where we, respectively, report the total received power (S_0) and the normalized Stokes parameters (s_1, s_2, and s_3) as acquired in a full day test. This test has been carried out having fixed the fibers in order to minimize the effect of parasitic stress, in almost constant environmental temperature and with the thermal stabilization of the laser diode switched on. As it can be seen comparing the curves in Fig. 2 and in Fig. 3, despite the thermal stabilization of the diode source, the total power shows a drift, not fully correlated with temperature variations, but the corresponding variation of the polarization state is almost irrelevant for our target application. However, this highlights that if the proposed system is used for the long-term evaluation of slowly varying phenomena, it is necessary to compensate for source power fluctuations and to design very stable electronic circuits, both for the source driver and the receiver.

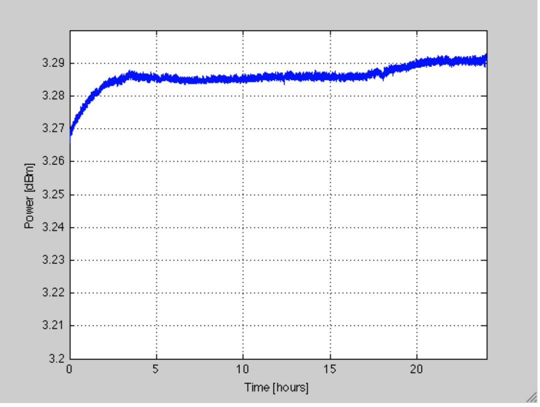


Fig. 2. Example of a stability test: received power in a 24 hour measurement campaign.

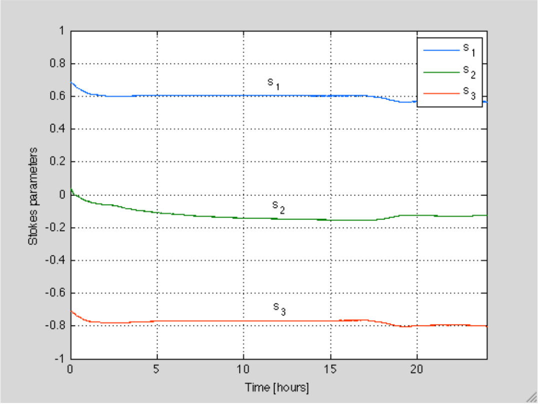
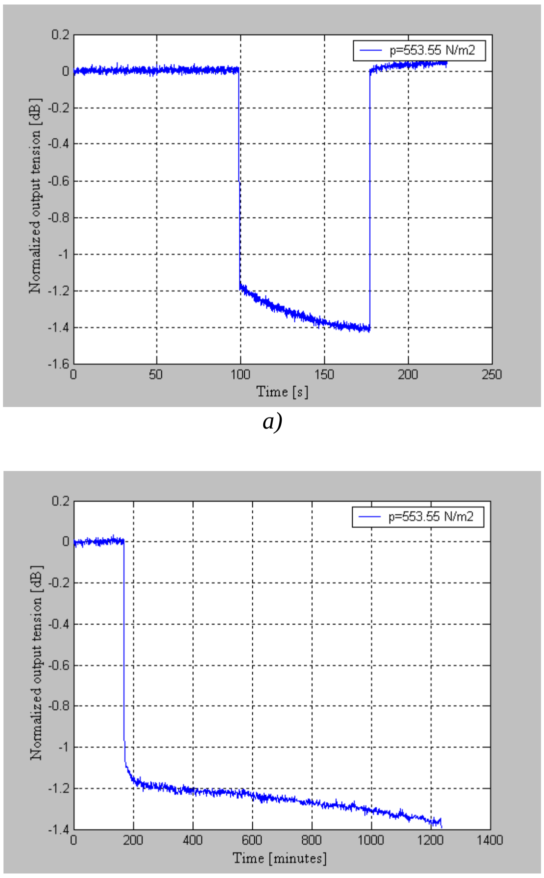


Fig. 3. Example of a polarization stability test: normalized Stokes parameters for the 24 hour test as in Fig. 2.

Then, as an example of practical application, Figs. 4 a)-b) and Fig. 5 present some readings obtained from a pressure sensor made by three loops of standard SMF embedded into a PMMA plate: Fig. 4-a) and Fig. 4-b) show the response obtained applying two steps of constant pressure (553.55 N/m^2) with different duration, whereas Fig. 5 reports the output for repeated pressure stimuli with different intensities.



a)

b)

Fig. 4. Examples of the pressure sensor responses when an abrupt pressure change is applied: a) pressure change lasting for about 3 minutes, and b) for 20 hours.

The response of the sensor to the applied stimulus is immediate, with a fast recovery once the stimulus is removed; in constant pressure conditions, however, the already mentioned received power drift in time is clearly evident (Fig. 4) making this sensor particularly suitable detecting pressure changes, without actually having to precisely measure the exact pressure value. Possible applications are therefore in the fields of safety and anti-intrusion, where the fiber can be used to sense the presence of people moving nearby.

The characteristic of the sensor has been evaluated recording the response at different pressures obtained with weights placed on the transducer (Fig. 5).

This procedure has been repeated several times, both increasing and decreasing the applied pressure, to evaluate also the repeatability and highlight possible hysteresis phenomena. The curves in Fig. 6 are almost overlapping straight lines, indicating negligible hysteresis and constant sensitivity, which are the typical requirements for high quality sensors. The sensitivity of the sensor in Fig. 4 is 1.15 dB/kg. Then, Fig. 7 reports the readings for a constant pressure as acquired during tests carried out in different days to study the stability of the setup and thus the repeatability of the measure. The obtained result is very good because the deviation is within 0.2% of the mean value.

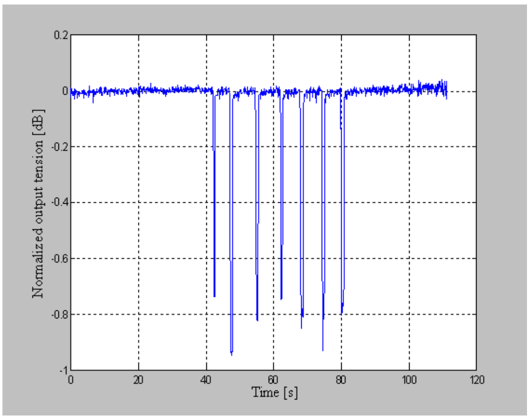


Fig. 5. Sensor response for different repeated stimuli.

It is well known that the variation of polarization in fiber depends also on the temperature [8], so a prototype of the developed sensor has been also tested in an environmental chamber, considering different temperature ranges up to from -10 to 50ºC. Of course, in the case of a sensor used to evaluate abrupt pressure changes, temperature produces only a bias at the output. However, it is important to evaluate the behavior of the sensing system when exposed to large temperature changes. Therefore, several cycles have been repeated and in each cycle the minimum and maximum temperature values have been maintained for one hour. The data acquisition system was programmed to register the sensor output every 20 seconds and no deformations have been applied.

Examples of the obtained resulted are shown in Fig. 8, where we report the curve of the temperature and the corresponding readings from the sensor in a 4 cycle test. The agreement between the two curves is very good, evidencing that the developed sensor could be used also to measure temperatures, although for this kind of application a further improvement in the circuit stability it may be necessary to compensate the slight drift that can be seen comparing the readings in the various cycles in Fig. 8.

Finally, in Fig. 9 we report a detail of the curves in Fig. 8 to show that the sensor response is in good agreement with the temperature variation profile.

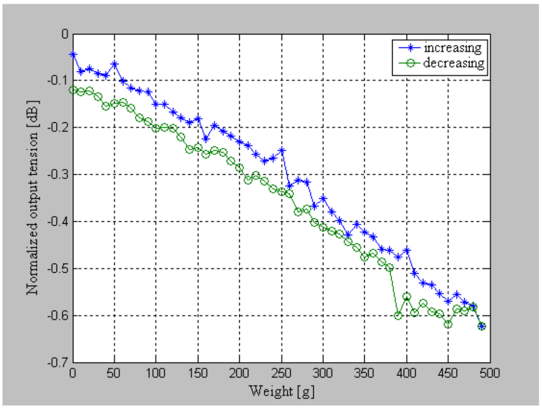


Fig. 6. Characteristic of the implemented sensor.

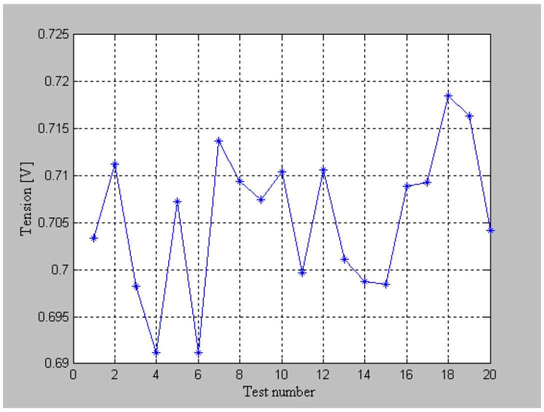


Fig. 7. Analysis of the sensor repeatability.

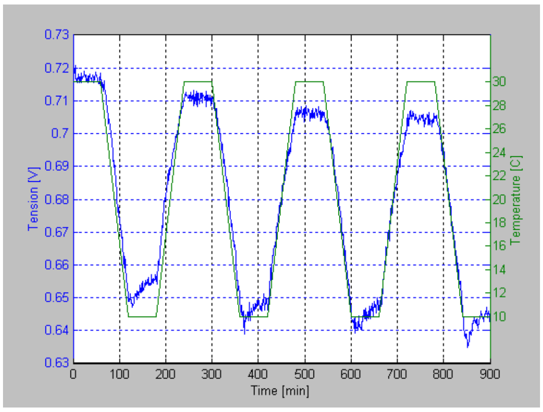


Fig. 8. Temperature behavior of the polarimetric fiber-optic pressure sensor over 15 hours.

3. Conclusions

A polarimetric fiber-optic pressure sensor based on the variation of the polarization state of light transmitted from a single-mode fiber has been presented. To keep the overall costs low, the measurement system is not based on an interferometric setup but on the direct evaluation of the power variation along a predefined linear polarization. Different sensitivities and working ranges can be obtained by modifying the embodiment of the transducer. The performances obtained in the specific example proposed make the device particularly suited for detecting abrupt pressure variations, such as those occurring in safety applications.

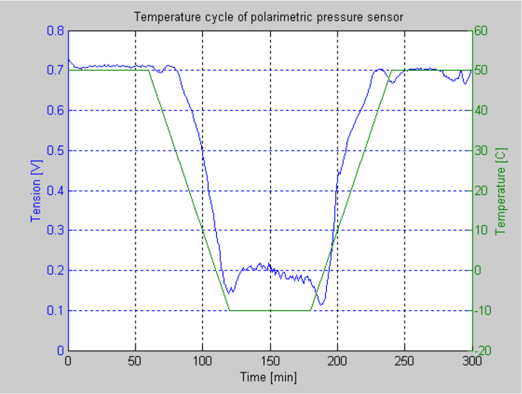


Fig. 9. Particular of the curves in Fig. 8.

References

[1] B. Culshaw, Journ. of Light. Technol. **22**(1), 39 (2004).

[2] G. C. Constantin, G. Perrone, S. Abrate, N. N. Puşcaş, J. Optoelectron. Adv. Mater. **8**(4), 1635 (2006).

[3] J. Noda, K. Okamoto, Y. Sasaki, Journal of Lightwave Technology, LT, **4**(8), 1071 (1986).

[4] A. W. Domanski, A. Gorecki, M. Swillo, IEEE Journal of Quantum Electronics, QE, **31**(8), 816 (1995).

[5] I. P. Kaminov, IEEE Journal of Quantum Electronics, QE, **17**(1), 15 (1981).

[6] Tomasz R. Wolinski, Artur Wyrwas, Andrzej W. Domanski, IEEE Instrumentation and Measurement, Technology Conference, Anchorage, AK, USA, 1129 (2002).

[7] Scott C. Rashleigh, Journal of Lightwave Technology, LT, **1**(2), 312 (1983).

[8] S. Yin, P. B. Ruffin, F. T. S. Yu, Fiber Optic Sensors, edited by CRC Press (2008).

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