Innovative safety monitoring system based on fiber optic sensors technology compatible with 4-20mA standard

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Abstract. In this contribution an innovative, full analog, fiber optic sensors (FOS) interrogator is designed which, being fully compatible with the 4-20 mA standard of the Programmable Logic Controller (PLC), enable the integration of the FOS technology in safety framework, such as the Detector Safety System (DSS) of the LHC Experiments. It is composed by a full analog electrical circuitry, capable to directly transduce the signal coming from the arrayed waveguide grating (AWG), into a monotonic electrical current in the range of 4- 20mA. In a first experimental analysis, a temperature of 50°C was detected, exhibiting an output trend which can be fitted with a 3rd order polynomial equation over the whole range. Furthermore, in a reduced range of 20°C, the trend behaves linearly. The proposed system has the potential to be fully integrated in the DSS of the LHC experiments. Indeed, a validation on field is foreseen in the framework of the Compact Muon Solenoid experiment DSS.

1. Introduction

Since the optical fiber is a passive and dielectric structure, a sensor written within it exhibit multiple advantages which cannot be reached with the classic electronic sensors. The typical fiber optic sensor (FOS) is light, passive, immune to electromagnetic interference, biocompatible, robust and with high measurement accuracy. One of the most employed FOS is the fiber Bragg grating (FBG) sensor, which is very sensitive for strain and temperature variations [1]. It behaves as an optical filter with a Gaussian trend, whose central wavelength is named Bragg wavelength and experiences a shifting if mechanical deformation or temperature variation occurs. They are widely studied in literature and are installed in a lot of environments: in the structure health monitoring of high buildings, towers, bridges etc., or in high energy physics [2], [3] to name a few. Despite the mentioned advantages, they are up to now not so diffusely used in the monitoring of industrial processes and are usually substituted with low performance but easier to manage sensors, in agreement with industrial monitoring standards. This slowdown is mainly caused by the limits of the interrogation system since are based on digital section for the processing data, decreasing the reliability and making them not suitable in those environments (as in the framework of CMS experiment [4]) in which a direct conversion between the physical phenomena and an electrical signal is required [5].

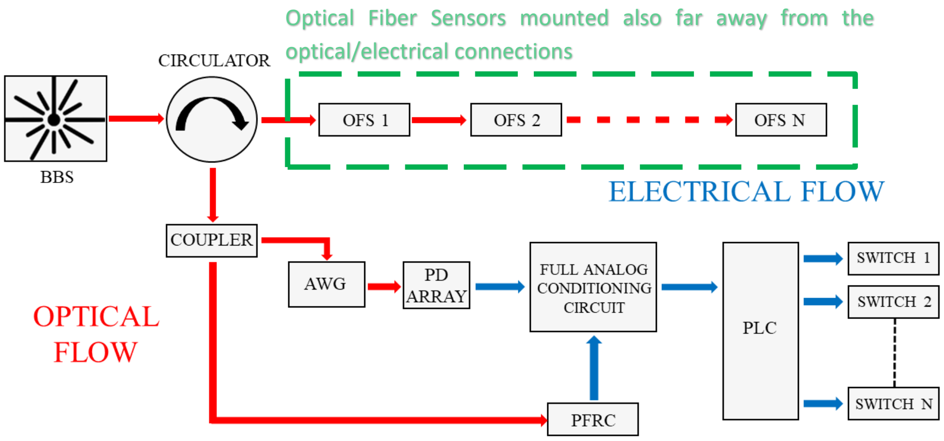

Figure 1. Block chain representative of the proposed system.

In literature, due to its intrinsic advantages, many arrayed waveguide grating-based interrogation systems have been investigated and designed: the arrayed waveguide grating (AWG) [6] is a passive device working as an integrated prism, casting a polychromatic input spectrum in many monochromatic output channels due to constructive and destructive interference, leading to a robust and reliable component in a compact package and with the possibility to produce it avoiding temperature dependence which may affect the output channels central wavelength. Furthermore, the AWG transmittance exhibits a Gaussian trend, easy to manipulate in convolution with other FOS presenting a Gaussian shape as well (FBG above all) [7]–[9]. To employ the device as optical demultiplexer and/or as optical filter, in substitution with other optical filters which needs control signal, gives the benefit to obtain an interrogation system without movable part and deprived of control signal, two features strongly limiting the measurement speed and the comprehensive reliability [10]. In this discussion, the AWG has been employed as main device for the design, characterization and realization of a safety monitoring system for FOS technology which is fully compatible with the Detector Safety System (DSS) employed at the CMS experiment [11]. The aim of the work was to design a full analog electrical circuitry in order to transduce the signal coming from the optical section of the system, into a monotonic electrical current whose variation is in the range of 4-20mA, in order to be read by a PLC system.

2. System Description

The system is depicted in figure 1 and is composed by an optical and electrical flow. From the optical point of view, a narrow part of the light signal generated by the source is back-reflected from one or more optical fiber sensors (installed also far away from the optoelectronic section), propagating towards an optical coupler, by means of an optical circulator, and, finally, in input to the AWG device. When the single sensor experiences a wavelength shifting, its spectrum will shift among the AWG channel transmittance, producing a change into the optical power monitored at the output of the single AWG channel. From the electrical point of view, a full analog conditioning circuit was projected ad-hoc to convert the optical power coming from the AWG output channel, in a current signal flowing towards an alarm switch or a PLC system. The mentioned circuit is completely protected from any kind of leakage current due to an optical isolator which has also the aim to reduce noise, if mounted in photovoltaic configuration. Moreover, thanks to the Power Fluctuation Rejection Circuit, the whole electrical circuitry has also the capability to restore the output if a source malfunction occurs or if a loss increment happens due to fiber bending or connector damaged. It was proved with experimental measurement that the full analog conditioning circuit can be employed either alone, to make a single channel measurement for the sensing variation of a physical quantity in the range of the single AWG channel transmittance, or combined to other circuit to increase the dynamic range of measurement (still exhibiting a monotonic trend), or to make a compensated measurement merging more FOSs response to get one physical quantity matched to the 4-20mA range.

3. Experimental Analyses

The system was tested in two different configuration: in 1-channel mode and in 2-channel mode to prove the capability to increase the dynamic range.

3.1. 1-channel measurement

An FBG sensor was employed to sense a temperature of 50°C measured with a FBG calibrated temperature sensor. The FBG has a Bragg wavelength of 1555nm, very close to the channel 28 peak at 1554.9nm. The temperature was changed due to a heat plate and the signal was acquired with a Digital Acquisition Board. In figure 3 the output current versus temperature range is shown, it exhibits a trend which can be fitted with a 3rd order polynomial equation over the whole range, with a resolution of 0.1°C/10µA at the low sensitivity region (starting and ending regions). Furthermore, in a reduced range of 20°C, the trend behaves linearly with a very high resolution (0.02°C/10µA). The purpose of the mentioned test was to simulate a possible scenario in which the proposed concept can be needed, obtaining an optimal result also in terms of stability. The proposed safety system was accepted for a trial in a pilot project stipulated with the CMS experiment at the CERN, in Geneve, since its peculiarities (robust, reliable and completely free from any digital processing section) allow it to be used as a safety monitoring system.

3.2. 2-channel measurement

An FBG sensors was employed to sense a temperature of 130°C measured with a FBG calibrated temperature sensor. The temperature was changed due to a heat plate and the signal was acquired with a Digital Acquisition Board. The FBG is the same as before but, in this case, in order to increase the dynamic range, the channels monitored was the 27 and 26: the channel 27 was monitored with a circuit calibrated with a certain gain, while the channel 26 was monitored with a higher gain electronic circuitry in order to ensure the increasing monotone trend shown in figure 3. This experimental analysis was led with the goal to prove the feasibility to increase the dynamic range of measurement if needed, in case the physical quantity to monitor provokes a Bragg wavelength shifting that is over a single AWG channel.

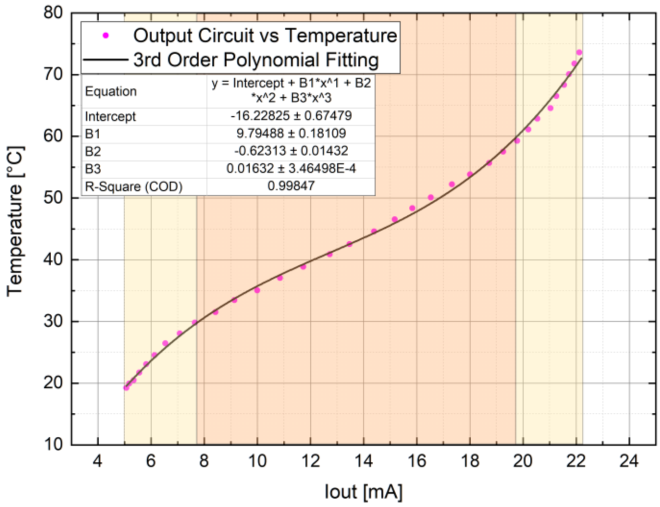

Figure 2. Current vs temperature trend for a 1-channel measurement, in which can be noted a 3rd order polynomial fitting.

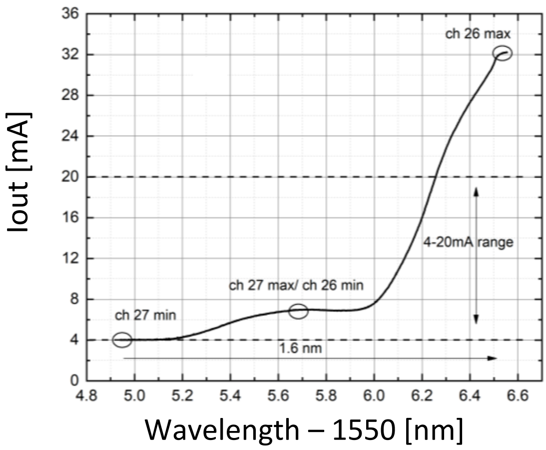

Figure 3. Output current in a 2-channel temperature measurement.

4. Conclusion

In this work a full analog monitoring system for fiber optic sensors has been designed and experimentally validated. The system is based on the AWG device, which works as a filter as well as a demultiplexer, directing the back-reflected signal from the sensor under test to a full analog electronic circuitry with a monotone trend. It is a fully passive device, not depending on temperature variation and with high robustness, making the whole system more reliable since is not needed any kind of control signal (e.g. as modulation signal for optical filter and/or tunable laser technology). The proposed concept has been validated with a 1-channel measurement, sensing a temperature variation of 50°C: as a first calibration the whole trend can be fitted with a 3rd order polynomial curve while, in the middle part, the shape is linear for more than 20°C. This latter result is very essential if applied in the framework of the DSS of CMS experiment in which a reliable monitoring system capable to sense a temperature deviation of 20°C is needed. Furthermore, the system has been proved with a 2-channel measurement in order to increase the dynamic range if needed just monitoring more than one AWG output channel. In Both cases the output is increasing monotone and in a range of 4-20mA ready for a PLC-based system in order to switch one or more alarm if the 20mA threshold has been overcame.

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