DATA AQUISINTION AND PROCESSING OF OPTICAL FIBER BRAGG GRATING SENSORS

Flaviu Birouas[1], Lehel Csokmai[2], Dan Ioan Țarcă[3], Radu Tarca[3]
[1]Mechatronics Department, University of Oradea, Oradea, Romania, fbirouas@uoradea.ro,
[2]Productica Research Centre, University of Oradea, Oradea, Romania, cs.lehel@gmail.com,
[3]Engineering Science Doctoral School, University of Oradea, Oradea, Romania, bh90tdi@gmail.com,
[4] Mechatronics Department, University of Oradea, Oradea, Romania, rtarca@uoradea.ro

Abstract**—** The work presented in this paper focuses on fiber brag grating (FBG) sensor data acquisition and measurements. A brief overview of the technology and of fiber bragg grating is presented as a basis of understanding of the experimental work. Hardware of the test system is presented in detail with its characteristics. Three distinct FBG sensors are presented, namely, temperature, strain and humidity. The experimental section tests these three sensors and a few observations are made about the testing implementation.

Keywords**—** Relative Humidity Sensor, Optical fiber, Fiber Bragg Grating, Data acquisition.

I. Introduction

THIS paper will discuss the implementation of a data acquisition and processing system for optical fiber bragg grating sensors (FBG). Optics plays a major role in modern measurement systems, providing considerable advantages over traditional electronic measurement equipment. Sensors based on optical fiber have benefits over conventional sensors such as reduced size, electrically passive immune to electromagnetic interference, long mean time before failure, and potential for large scale multiplexing. Measurements can be performed over long distances (up to 10 km) without loss of signal accuracy. A widely used type of sensors fall under the subdomain of the fiber bragg sensors (FBG). These type of sensors have a wide variety of applications including the monitoring of civil structures, smart manufacturing, non-destructive testing, remote sensing, as well as traditional strain, pressure, humidity and temperature measurements.[1,2]

This paper covers theoretical notions and experimental testing regarding FBG sensor measurements. Implementation and demonstration of a data acquisition is exemplified using temperature, strain and humidity sensors.

II. Optical properties of FBGs

Since the temperature, strain and humidity FBG sensors are used to demonstrate the application a brief overview of the underlying physical mechanisms of FBG is presented in this chapter. The optical properties of FBG sensors are presented as the basis for understanding the data acquisition process later on.

Temperature and strain FBG sensors is discussed in the non-coated FBG sensors section while the humidity FBG sensor is discussed in the FBG coated sensor section.

A. Non-Coated FBG sensors.

A FBG sensor is a type of distributed Bragg reflector constructed in a short segment of optical fiber that reflects specific wavelengths of light and transmits all the other components. [3] The basic concept of FBG sensors is illustrated in figure 1.

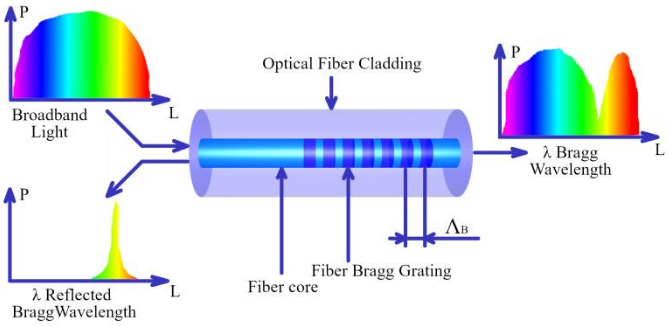

Fig. 1 Basic FBG sensor functionality.

Fiber Bragg Gratings are formed when a refractive index modulation is produced in a fiber core. When a broadband pulse is propagated down an optical fiber, a narrow wavelength of the pulse is reflected back while the remaining spectrum is transmitted. The wavelength of the light reflected depends on the spacing of the braggs, noted as Λ_B, and the effective refractive index of the modulations, noted as n_e. The Brag reflection wavelength can be determined using expression (1).

$$\lambda_B = 2n_e\Lambda_B \qquad (1)$$

Where n_e, denotes the effective refractive index of fiber core[4], and is determined from expression (2).

$$n_e = \frac{n_{\max} - n_{\min}}{2} \qquad (2)$$

Strain or temperature changes cause the spacing between the braggs Λ_B to vary, this variation in turn leads to a change in the Bragg reflected wavelength, λ_B.

As both temperature and strain can change λ_B it becomes necessary to distinguish between the two effects if they are to be accurately measured. This is done by using two Bragg gratings made of different materials, allowing the two effects to be distinguished [2,5]. As strain or temperature is applied, the λ_B factor changes from its initial wavelength to a shifted wavelength. The variation in wavelength, $\Delta\lambda_B$, due to this shift is what allows the strain and temperature to be determined, as expressed by (3).

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - p_e)\varepsilon + \left((1 - p_e)\alpha_\Lambda + \alpha_n\right)\Delta T \qquad (3)$$

Where:

p_e is the effective strain optic coefficient,

ε is the strain on the fiber,

α_Λ is the thermal expansion coefficient of the fiber,

α_n is the thermos-optic coefficient of the fiber and ΔT is the change in temperature [1,2,6].

B. Coated FBG sensors

Fiber Bragg gratings are ideally suited for very accurate strain and temperature measurements. However, by applying of a polymer coat FBGs can be used to determine molecule concentrations. [7] The polymer-coated FBGs indicate linear shifts in the Bragg resonance wavelengths of the gratings with temperature [3], or the presents of molecules that produce physical changes in the polymer such as swelling or dilatation. These type of FBG sensors are well-suited applications where determining the relative humidity (RH) is needed. [1]

In the case of sensing relative humidity, the coating swells and strains the underlying optical fiber containing the Bragg grating, as shown in figure 2.

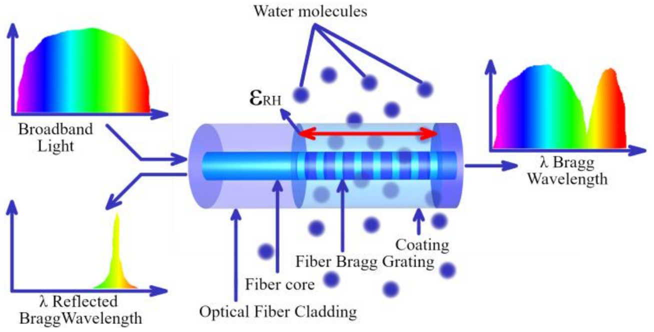

Fig. 2 RH FBG coated sensors.

The process of coating the FBG involves stripping the existing factory made coating then coating the fiber with an enhanced humidity sensitive coating.

When using FGBs as humidity sensors an equation can be formed based on (3) that describes the change in Bragg reflection wavelength influenced by humidity and temperature [2,4], as expressed in (4). [7]

$$\frac{\Delta\lambda_B}{\lambda_B} = (1-p_e)\varepsilon_{RH} + \left[(1-p_e)\varepsilon_T + \alpha_n\right]\Delta T \quad (4)$$

Where ε_{RH} and ε_T represent the strain induced on the fiber as a mechanical strain generated by the polymer swelling due to moisture and thermal expansion respectively. This is done assuming that molecular composition of the medium does not offset drastically the measurement, introducing swelling deformations generated by molecules other than H_2O that are present in the air.

For humidity measurements at a constant temperature, the second term of equation (4) may be ignored and the expression simplifies to (5).

$$\frac{\Delta\lambda_B}{\lambda_B} = (1-p_e)\varepsilon_{RH} \quad (5)$$

The moisture-induced strain caused by RH can also be further described as (6).

$$\varepsilon_{RH} = \frac{A_p E_p}{A_p E_p + A_f E_f}\left(\alpha_p(RH) - \alpha(RH)\right)\Delta RH \quad (6)$$

Where:

A represents the cross sectional area of the material,

p and *f* subscripts represent the polymer and fiber respectively,

E is Young's modulus of the material,

α is the coefficient of moisture expansion [1].

Prior work shows that polyimide coatings have potential to be used as active coating for Bragg grating humidity sensors [1,5], as a result a polyimide coated FBG sensor is used to demonstrate implementation the acquisition system for determining relative humidity.

III. Materials and Methods

A. Hardware components

This section lists and describes briefly the hardware equipment used to elaborate the experimental setup. The data acquisition system is presented in figure 3.

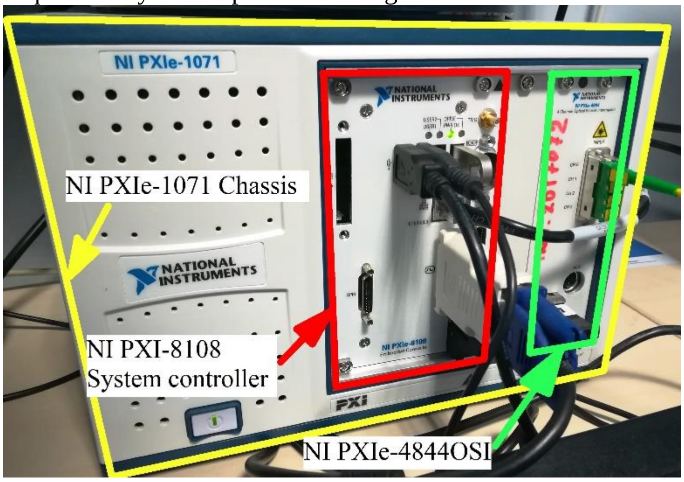

Fig. 3 Data acquisition hardware.

The components used are as following:

1) NI PXIe-1071 Chassis

Equipped with 4 PXI Express slots, of which 3 are PXI Express Hybrid Peripheral Slots, and 1 is a PXI Express System Controller Slot

2) NI PXI-8108 System controller

This module is an integrated PC, with x86 architecture with the addition of some specialized peripheral integrated for equipment interfacing, instrumentation and data acquisition applications. The specifications are:

- Express Card slot
- IEEE 1284 ECP/EPP parallel port
- -GPIB (IEEE 488) controller
- RS232 serial port

3) NI PXIe-4844 Optical Sensor Interrogator

The NI PXIe-4844 optical sensor interrogator is a specialized data acquisition module used for measuring fiber Bragg Grating optical sensors. It interfaces as a dual-slot 3U PXI Express.

It is possible to daisy chain FBGs with different nominal Bragg wavelengths within a single optical fiber as long as each FBG occupies a unique wavelength range within the 80 nm optical spectrum of the NI PXIe-4844.

Module capabilities:

- 4 optical channels,
- Simultaneous sample rate 10 Hz,
- Absolute wavelength range 1510 – 1590 nm (80nm range),
- Maximum number of FBG sensors per channel 20 (80 per module).

B. Software

This section lists and describes briefly the software packages used to elaborate the experimental setup. The packages are as following:

1) NI-OSI Explorer

NI-OSI short for *Optical Sensor Interrogator*, this software package is used as a configuration interface for the NI PXIe-4844 module. This configuration manager can scan the optical wavelength range in order to identify all connected FBG sensors. Here the scaling configuration are made and exported for use in the NI-OSI LabVIEW API. Data is returned as an array that is directly passed through the LabVIEW environment. Software Compatibility: LabVIEW Development System and LabVIEW Real-Time Module.

2) LabVIEW

LabVIEW short for *Laboratory Virtual Instrument Engineering Workbench*, developed by National Instruments, is used as a programming environment for building the application.

IV. Application

This chapter describes the application setup, configuration and deployment. Channel number, range, and scaling equations are configured for all FBG sensors using the NI-OSI Explorer. After configuring, all scans automatically parse the channel data into individual sensor measurements and scale the data into appropriate engineering units. The block diagram of the application is presented in figure 4, where:

- Block 1 creates or replaces a file to store the output data.
- Block 2 create an OSI Task and import sensor data from the OSI Explorer Configuration File.
- Block 3 sets the OSI Sample Mode to continuous.
- Block 4 sets some file properties such as Author, Time Stamp and Sample Rate.
- Block 5 calls the Start VI to start the acquisition process.
- Block 6 uses the Read VI too measure multiple samples from N channels on the device. It also sets a timeout so an error is returned if the samples are not returned in the specified time limit.
- Block 7 saves the waveforms to TDMS file. Note that channel names and units are waveform attributes.
- Block 8 reads back the actual sample rate.
- Block 9 closes the file.
- Block 10 Calls the Clear Task VI to clear the Task.
- Block 11 Uses the popup dialog box to display an error if any.

The TDMS file format is opened using a dedicated plugging from National Instruments for Microsoft Excel Spreadsheet. From this data, measurements graphs is plotted and analyzed.

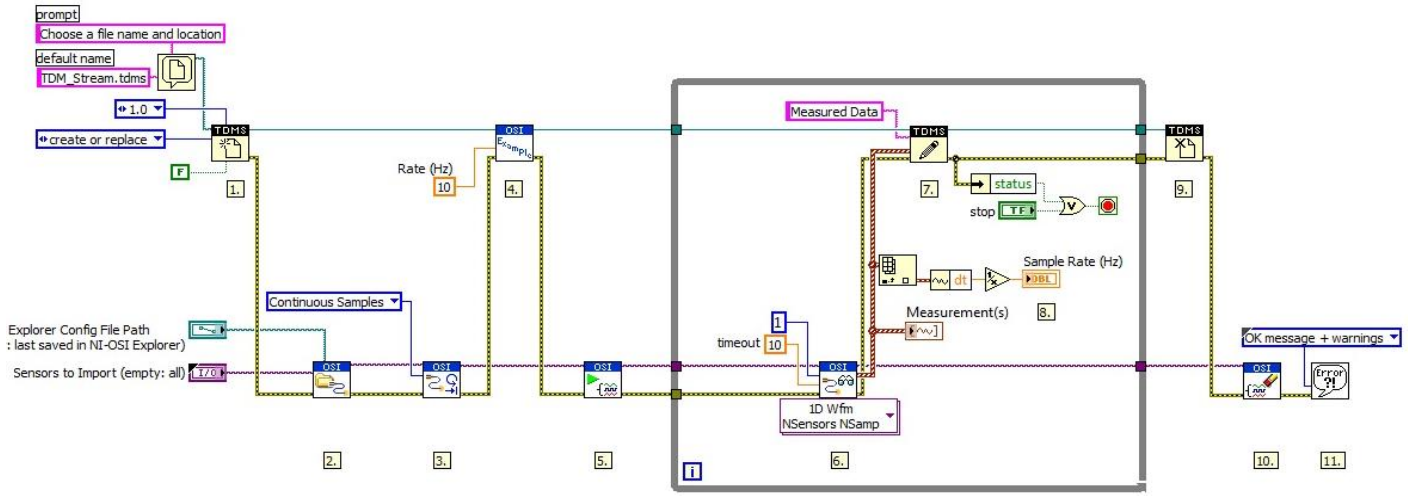

Fig. 4 LabVIEW Block Diagram of the data acquisition system.

V. Measurements

In this chapter, measurements are performed using the implemented data acquisition system on the three distinct FBG sensors: stress, temperature and relative humidity. The sample rate is set to 10Hz and the data is collected.

The temperature measurements are presented in figure 5.

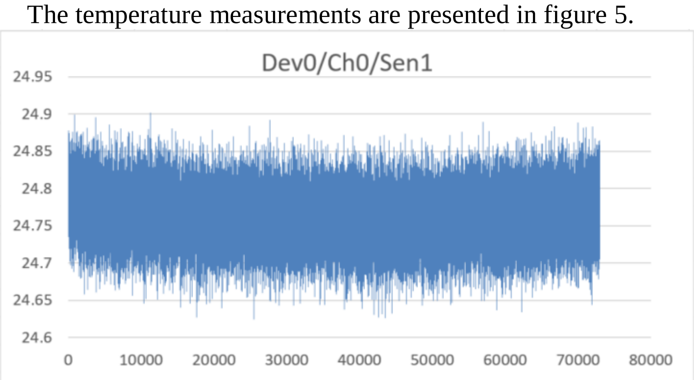

Fig. 5 Temperature FBG sensor measurement graph. Where the X-axis represents the number of samples and Y-axis the temperature in degrees Celsius.

During the testing of all the sensors the temperature was held constant throughout the experiment. The laboratory ambient temperature determined after approximately 75000 samples is between 24.9 and 24.62 degrees C.

The strain FBG sensor is manufactured by HBM and comes in a composite outer enclosure as illustrated in figure 6.

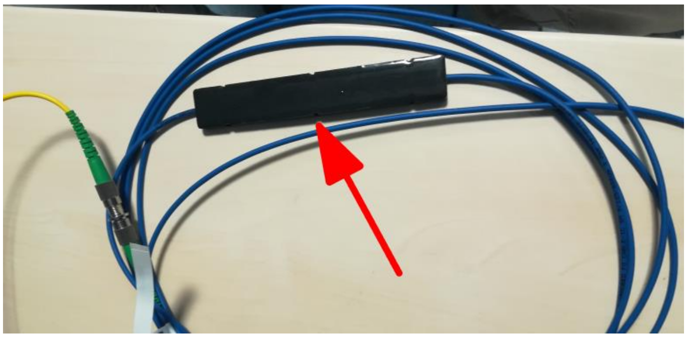

Fig. 6 Strain FBG sensor.

A data acquisition test is made using the implemented system. An approximate 550 samples were recorded. The outputs data can be seen in figure 7 were force was applied on both directions.

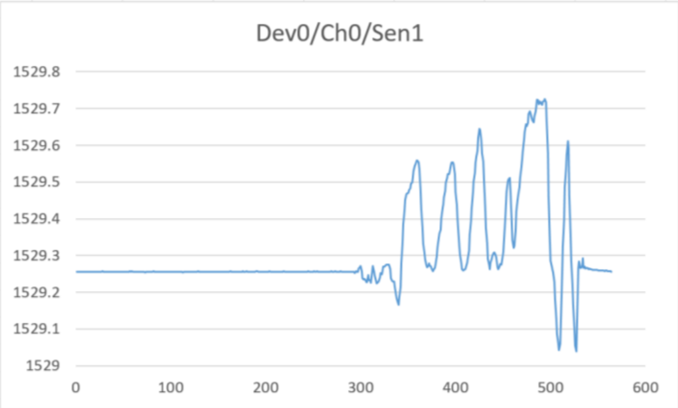

Fig. 7 Strain FBG sensor measurement graph. Where the X-axis represents the number of samples and Y-axis the wavelength in nm.

The RH FBG sensor was tested using an approximate 75000 samples, as seen in figure 8 the relative humidity measurement stabilizes after an approximate 10000 samples or roughly 16 minutes based on the 10Hz sample rate. This is due to the polyimide coating needing time to absorb the water molecules.

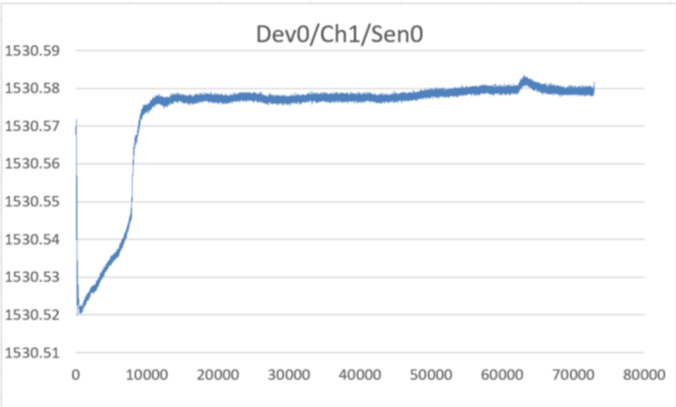

Fig. 8 RH FBG sensor measurement graph. Where the X-axis represents the number of samples and Y-axis the wavelength in nm.

VI. Conclusion

The test implementation presented has potential uses in numerous applications where precise data interrogation is needed, some possible applications are:

- Water concentration monitoring in alcoholic beverages fermentation process[8,9],
- Air quality monitoring,
- Processes where temperature and humidity are critical,
- Complex strain measurements where large number of measurement point are needed,
- Biofuel monitoring.

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