Optics Lab #2 Optical Interrogator

Using Fiber Bragg Gratings to Measure Mechanical Properties

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In this experiment you will utilize the properties of fiber optic cables and fiber Bragg gratings (FBGs) to measure the mechanical properties of an aluminum rod.

I. INTRODUCTION

A. Industrial Uses

Fiber Bragg gratings (FBGs) are commonly used in industry. While the most common uses are monitoring large structures such as bridges, pipelines, radio towers, buildings, and tunnels, FBGs have also found uses in aerospace and biomedical devices. Their ability to provide a wide variety of measurements, including strain, temperature, pressure, displacement, and acceleration, make it a very versatile technology.

FBGs work in conjunction with an optical interrogator. The optical interrogator sends a wide spectrum of light down a fiber optic cable. Each fiber brag grating reflects a specific wavelength back. The optical interrogator measures the intensity of the reflected light over the entire spectrum, and can identify the peaks in intensity that correspond to the reflected wavelengths. As the specific wavelength each FBG reflects changes with what it measures, the optical interrogator can interpret these slight wavelength shifts for each type of sensor.

FBG technology has many advantages over other types of sensors. Because fiber optic cable is very efficient at carrying light, the distance between sensors can be places several 10s of kilometers away from the optical interrogator. Because FBG sensors work by reflecting light, they do not require a power source. Additionally, they do not require regular recalibration.

A prime example of how FBGs can be used to measure the structural stability of a building can be found at (http://www.micronoptics.com/document_library/case_studies/civil_structures/Case_Study_Chulitna_Bridge_20130530.pdf).

B. Strain

Strain is a measure of how an object deforms over its length, as shown in Equation 1.

$$\epsilon = \frac{\Delta L}{L} \tag{1}$$

Since both the numerator and denominator are measured in meters, strain is technically dimensionless. Strain is most commonly measured in units of microstrain which is the change in length (in micrometers) per meter; Equation 2.

$$\mu\epsilon = \frac{\mu m}{m} \tag{2}$$

Monitoring of strain in structural applications is very important because after a metal deforms too much, the properties of the metal will begin to change. Typically a metal will grow harder, and more brittle, but as the deformation increases, it will eventually start to weaken and then break.

C. Fiber Bragg Gratings

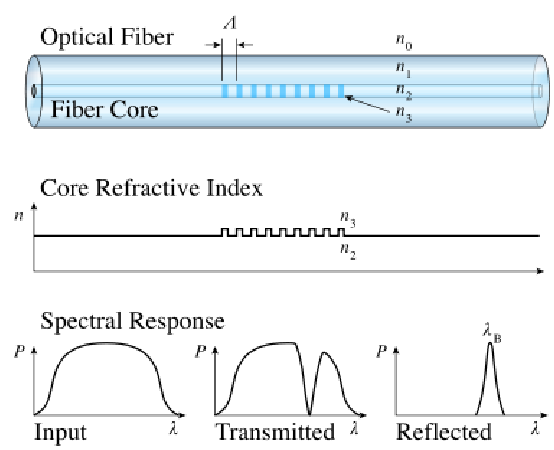


FIG. 1. [1] A Fiber Bragg Grating structure, with refractive index profile and spectral response.

The following has been adapted from "Strain Measurement with Fiber Bragg Grating Sensors" [2]

The cable is made of glass fibers, which totally internally reflect light sent through it parallel to the length of the cable. The cable consists of a small inner core of diameter 4 to 9 μm, and an outer cladding of 125 μ m. The inner core is doped with Germanium to increase the index of refraction, and the outer cladding is pure glass. The sm125 operates by sending light at a wavelength of 1510 to 1590 nm down the cable, which actually travels only in the inner core. At the end of the cable, regardless of its length, is a series of thousands of bragg gratings. These are created by UV etching. Each of these only reflect 0.001% to 0.1% of the incident light. Due to interference, much of the light is erased in the backward direction, but continues forward interfering constructively, so that there is a strong reflected peak. The location of this peak is controlled by the spacing of the gratings. Altering the grid spacing affects which wavelengths add constructively and which add destructively. This is shown in figure 1

Light will add constructively if an integer multiple of its wavelength fits into twice the grid spacing, because the light travels forth and back. The grid spacing G is then

$$G = \frac{\lambda_0}{2n} \tag{3}$$

with n = 1.46 for a typical fiber. As will be explored later, different sensors have a different designed λ_0. If, for example, λ_0 = 1500 nm, then G = 530 nm. In practice, the grid spacing and index of refraction change with strain and temperature. This will cause λ to shift in accordance with equation 3. The wavelength shift of the reflected peak will then be given by

$$\frac{\Delta\lambda}{\lambda_0} = k\epsilon + \alpha_\delta \Delta T \tag{4}$$

where

$$\Delta\lambda = \text{wavelength shift}$$

$$\lambda_0 = \text{Initial wavelength}$$

$$k = 1 - p \tag{5}$$

$$p = \text{photo-elastic coefficient} = 0.22$$

$$k = \text{gage factor} = 0.78$$

$$\epsilon = \text{strain}$$

$$\Delta T = \text{Temperature change in K}$$

$$\alpha_\delta = \text{change in refractive index}$$

$$\alpha_\delta = 5 * 10^{-6}\ K^{-1} \text{ to } 8 * 10^{-6}\ K^{-1}$$

$$\alpha_\delta = \frac{\mathrm{d}n}{\mathrm{d}T}\frac{1}{n} \tag{6}$$

In equation 4, the expression $k\epsilon$ describes both the mechanical and thermal strain. The expression $\alpha_\delta \Delta T$ describes the change in the index of refraction due to the temperature only. The total strain, ϵ, is equal to $\epsilon_m + \epsilon_T$, where m and T stand for mechanical and thermal. The thermal strain is given by $\epsilon_T = \alpha_{sp}\Delta T$, where α_{sp} is the expansion coefficient per K of the sample. Inserting these into equation 4 results in

$$\frac{\Delta\lambda}{\lambda_0} = (1-p)(\epsilon_m + \alpha_{sp}\Delta T) + \frac{\mathrm{d}n}{\mathrm{d}T}\frac{\Delta T}{n} \tag{7}$$

$$\frac{\Delta\lambda}{\lambda_0} = k(\epsilon_m + \alpha_{sp}\Delta T) + \alpha_\delta \Delta T \tag{8}$$

where, for example

$$\alpha_{sp} \text{ for aluminum} = 22\text{to}23 * 10^{-6} K^{-1}$$

$$\alpha_{sp} \text{ for steel} = 11\text{to}13 * 10^{-6} K^{-1}$$

In the case of a temperature sensor, there will be no mechanical strain, so equation 7 becomes

$$\frac{\Delta\lambda}{\lambda_0} = (1-p)\alpha_{glass}\Delta T + \frac{\mathrm{d}n}{\mathrm{d}T}\frac{\Delta T}{n} \tag{9}$$

where α_{glass} = the thermal expansion coefficient of the fiber = $0.55 * 10^{-6} K^{-1}$. Equation 9 can be rewritten as:

$$\frac{\Delta\lambda}{\lambda_0} = (k\alpha_{glass} + \alpha_\delta)\Delta T \tag{10}$$

$$\Delta T = \frac{1}{k\alpha_{glass} + \alpha_\delta}\frac{\Delta\lambda}{\lambda_0} \tag{11}$$

Temperature will have a much greater impact on the change of the index of refraction of glass than it will on the thermal expansion. In the case of a strain sensor, however, the sensor is constrained to expand with the material it is affixed to, and equation 8 is used. Rearranging equation 8 to solve for mechanical strain, we get

$$\epsilon_m = \frac{1}{k}\frac{\Delta\lambda}{\lambda_0} - (\alpha_{sp} + \frac{\alpha_\delta}{k})\Delta T \tag{12}$$

D. Temperature Compensation

Thermal effects manifest in any sensor, and it is impossible to differentiate the source of a wavelength shift with a single FBG. It is common in practice to use two separate sensors to compensate for the effect of the temperature.

An FBG can be affixed to a portion of the material being tested that is not under mechanical strain. The wavelength shift and temperature shift will then be due solely to thermal effects, which can be calculated as follows:

$$\frac{\Delta\lambda}{\lambda_0} = (k\alpha_{sp} + \alpha_\delta)\Delta T \tag{13}$$

$$\Delta T = \frac{1}{k\alpha_{sp} + \alpha_\delta}\frac{\Delta\lambda}{\lambda_0} \tag{14}$$

These effects can be subtracted from the sensor measuring strain, and ideally this would eliminate the affect of temperature on the strain sensor. Then equations 13 and 14 become

$$\frac{\Delta\lambda_m}{\lambda_{0m}} - \frac{\Delta\lambda_c}{\lambda_{0c}} = k\epsilon_m \tag{15}$$

$$\epsilon_m = \frac{1}{k}\frac{\Delta\lambda_m}{\lambda_{0m}} - \frac{\Delta\lambda_c}{\lambda_{0c}} \tag{16}$$

Where the subscript "m" stands for mechanical, and "c" stands for compensation. In the case where there is no portion of the object being measured that is not under mechanical strain, then the following must be used:

$$\epsilon_m = \frac{1}{k}\left(\frac{\Delta\lambda_m}{\lambda_{0m}} - \frac{\Delta\lambda_T}{\Delta\lambda_{0T}} * \frac{k\alpha_{sp} + \alpha_\delta}{k\alpha_{glass} + \alpha_\delta}\right) \quad (17)$$

Since $\alpha_\delta >> k\alpha_{glass}$, $k\alpha_{glass}$ can be neglected. Equation 17 becomes

$$\epsilon_m = \frac{1}{k}\left(\frac{\Delta\lambda_m}{\lambda_{0m}} - \frac{\Delta\lambda_T}{\Delta\lambda_{0T}}\left(\frac{k\alpha_{sp}}{\alpha_\delta} + 1\right)\right) \quad (18)$$

The preceding was adapted from ”Strain Measurement with Fiber Bragg Grating Sensors” [2]

E. Sensors

At the NIU optics lab, we have the following sensors:

- os3200 strain gauge
- os4200 temperature gauge
- os4210 temperature gauge

Included in the appendix of this document are the specification sheets for these components. In a temperature compensation experiment, the os3200 should be epoxied to the object being measured, located and oriented such that linear strain is measured at the desired portion of the object. As the object is put under strain, the FBG spacing will increase, and the wavelength will shift in accordance with equation 4. The os4200 or os4210 can be attached nearby to a portion not under mechanical strain. Applying equation 18 should produce the mechanical strain. While these calculations can be done by hand, software can be used to do these calculations in real time.

II. LABORATORY SETUP

A. Interrogator Setup

The optical interrogator used in this experiment is the sm125 from micron optics, and is shown if Figure 2. The sm125 power supply is plugged into the rear of the device. When the device is powered the red ”power” light will illuminate on the front of the sm125 modual. The LAN port needs to be connected via an Ethernet cable to the same switch as the computer used to interface with the interrogator (more information on this is provided in the Network Setup section below). Each FBG sensor is plugged into one of the four channels on the right of the sm125. To ensure proper alignment and seating each of the fiber optics connectors as a ridge as shown in Figure 3 that must be aligned with the notch on the channel port.

FIG. 2. *The sm125 from Micron Optics* The sm125 is the optical interrogator used in this investigation. It provides the interface between the FBG sensors and the computer.

FIG. 3. *Fiber Connection Plug* Each of the fiber connectors are plugged into the channel receptors. Note that there is a ridge on the side of the fiber connector that must be aligned the notch on the channel port.

B. Network Setup

The optical interrogator communicates to the computer through IP protocols. In industry this allows monitoring a network of interrogators from several locations. Setting up a dedicated network is outside the scope or needs of this experiment, but the computer still needs to connect to the optical interrogator over the Ethernet. Direct connection from the optical interrogator to the computer is only possible when using a crossover cable, so instead both the interrogator and the computer need to be connected to an Ethernet switch. (Switches are similar to routers, however, In general a switch manages traffic within a network and a router manages traffic entering and exiting a network.) The computer now needs to be assigned the appropriate Netmask and IP Address. The computer needs to be assigned an IP address of 10.0.0.121 and Netmask 255.255.255.0.Instructions

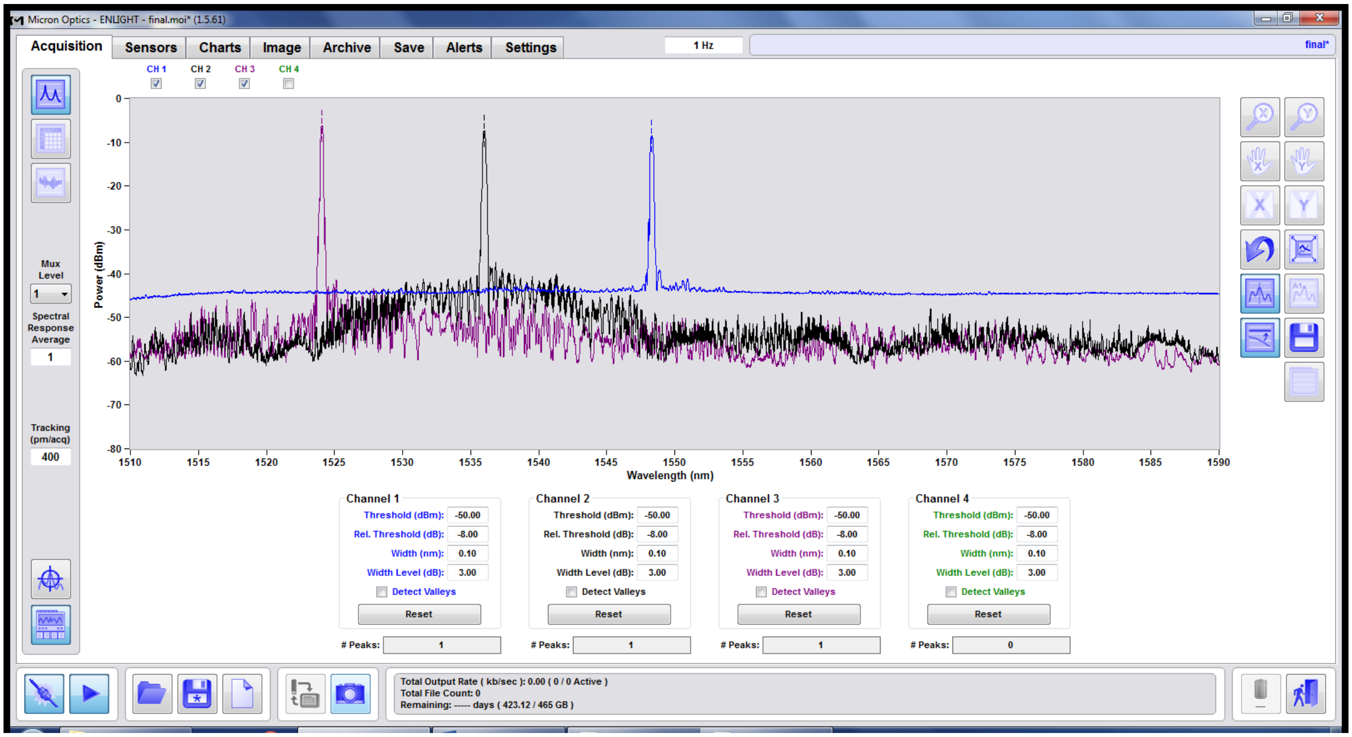


FIG. 4. *The Acquisition Tab* The acquisition tab of the Enlight software is shown here. Each corresponds to the reflected wavelength of one of the FBGs.

C. Enlight Software

1. *Acquisition Tab*

The acquisition tab, shown in Figure 4 shows the reflected wavelength for each of the sensors. Each of the wavelengths reflected by each of the FBG sensors is represented as a peak here. Each channel and sensor can be isolated by selecting individual channels in the upper left hand corner. The criteria for a peak to be recognized as such can be set separately for each channel using the dialogue boxes beneath the graph. The buttons on the right can be used to zoom in on individual peaks.

2. *Sensor Tab*

The sensors tab shown if Figure 5, converts the peaks that were shown on the acquisition tab into the physical quantities they represent. First the peaks must be named and their ranges identified. The window to do this is brought up by clicking on the "Create FBGs" icon in the upper middle of the sensor tab window (it looks like a 3 dimensional peak with two arrows on each side). This will let the user define the resting wavelength for each sensor and the wavelength range that particular sensor will occur over. In industry, the fiber for each channel will likely have many different FBG sensors, and it is necessary to let the Enlight software use the default wavelength and wavelength range for each sensor, so the software will be able to track each peak correctly. Here, because only one sensor is used per channel, the range of each peak can be set quite wide.

To create a new sensor, click the "Create From Definition" button. This will allow the loading of the presets for any of the sensors developed by micron optics. When opened, the sensor setup tab will still require that the sensor be named, the FBG defined, and the particular constants enumerated. The diologue boxes in the middle of the right column are used to choose which of the FBG peaks defined and named on the sensor tabs corresponds with this sensor. The constants that are used to populate the boxes in the left column vary from sensor to sensor, and are included as appendices to this manual. With the type of sensor now defined, associated with the corresponding peak, and its individual coefficients of collaboration defined, the Enlight software can now convert the reflected wavelengths to the physical properties they are measuring.

3. *Charts Tab*

With the properties of each sensor defined on the sensors tab, the charts can now be charted in real time. through the use of the charts tab, shown in Figure 6. The charts tab can show the output of multiple sensors simultaneously in real time. To choose the data each

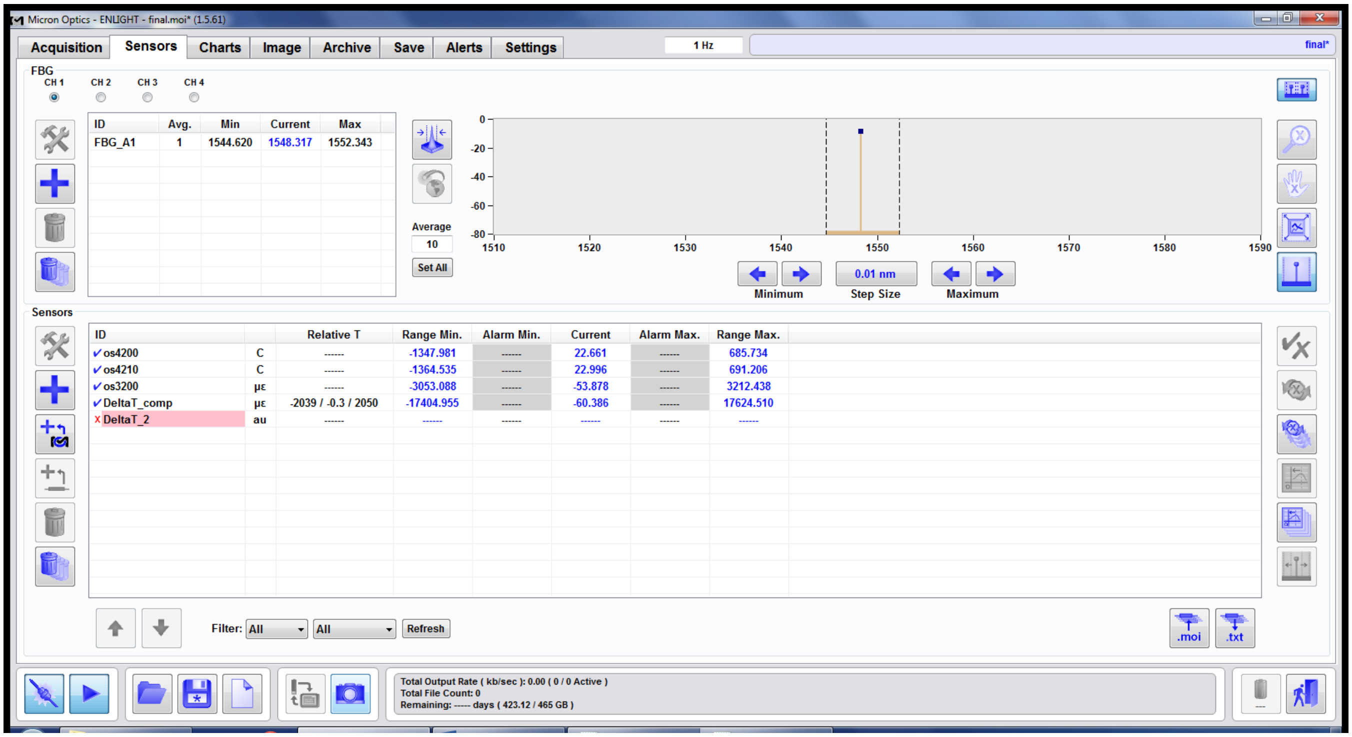


FIG. 5. *The Sensors Tab* The sensors tab of the Enlight software is shown here. The top half of this screen is used to define the chariceristics of each peak, and the bottom half uses those defined peak to define the charctersitics of each sensor.

sensor displays, select the data type (ie. strain or temperature) from the pull down menu on the left. From there the specific sensor (named on the sensors tab) can be selected. By default each chart scales automatically to show the entirety of the data. For example in Figure 6 the two temperature charts are measuring an unchanging temperature, and therefore have a very limited range in the displayed temperature. If one of the two probes were to be dipped in cold water, the chart would rescale to accommodate the wider temperature range. The scaling can also be set manually, with the scaling icons to the left of the charts. The charts can also be reset to start a new data run, either individually or en mass. To reset a particular chart click on the clock icon, to reset all simultaneously, click on the icon with multiple clocks in the upper left hand corner.

III. EXPERIMENTAL PROCEDURE

A. Setup

In the optics lab is a rectangular aluminum bar, measuring 750x6x6 mm. Affix the os3200 to the center of the bar, parallel to its length. This can be done using either electrical tape, or if permission is granted, epoxy. Note that the epoxy is permanent, and the sensor cannot be recovered after its use. Then attach either the os4200 or the os4210 on the adjacent side of the bar, centered and parallel to its length as before. The temperature probe not used can be left in the air to be used as background.

Plug in all of the sensors, and open up the software. Using the peak detection software described previously, detect the spectral peaks, and create the relevant FBGs from definition. Make sure that the temperature FBGs display reasonable values, such as 20 to 25 degrees celsius. The os3200 FBG will measure in microstrains, and a small degree of noise is to be expected. This FBG should be zeroed when the bar is under zero mechanical strain, e.g. resting on the table.

The bar can be rested at each end on two pulled-out drawers, such that there is another drawer not pulled out in the center. This will use most of the length of the bar. Orient the bar such that the os3200 is facing the floor. Acquire a mass holder, and several 100g masses. The mass holder should be hung at the center of the bar, directly above the os3200. Do not add weight yet. This will be called the initial configuration.

At this point, one can either create sensors in the software to display the total strain and the temperature-compensated mechanical strain, or simply save the raw FBG data and later edit the data. Either way, equation 4 is to be used to find the total strain, and equation 16 is to be used to find the mechanical strain. If one is using sensors to obtain this data, these equations are to be put into the "expressions" in the edit sensor window.

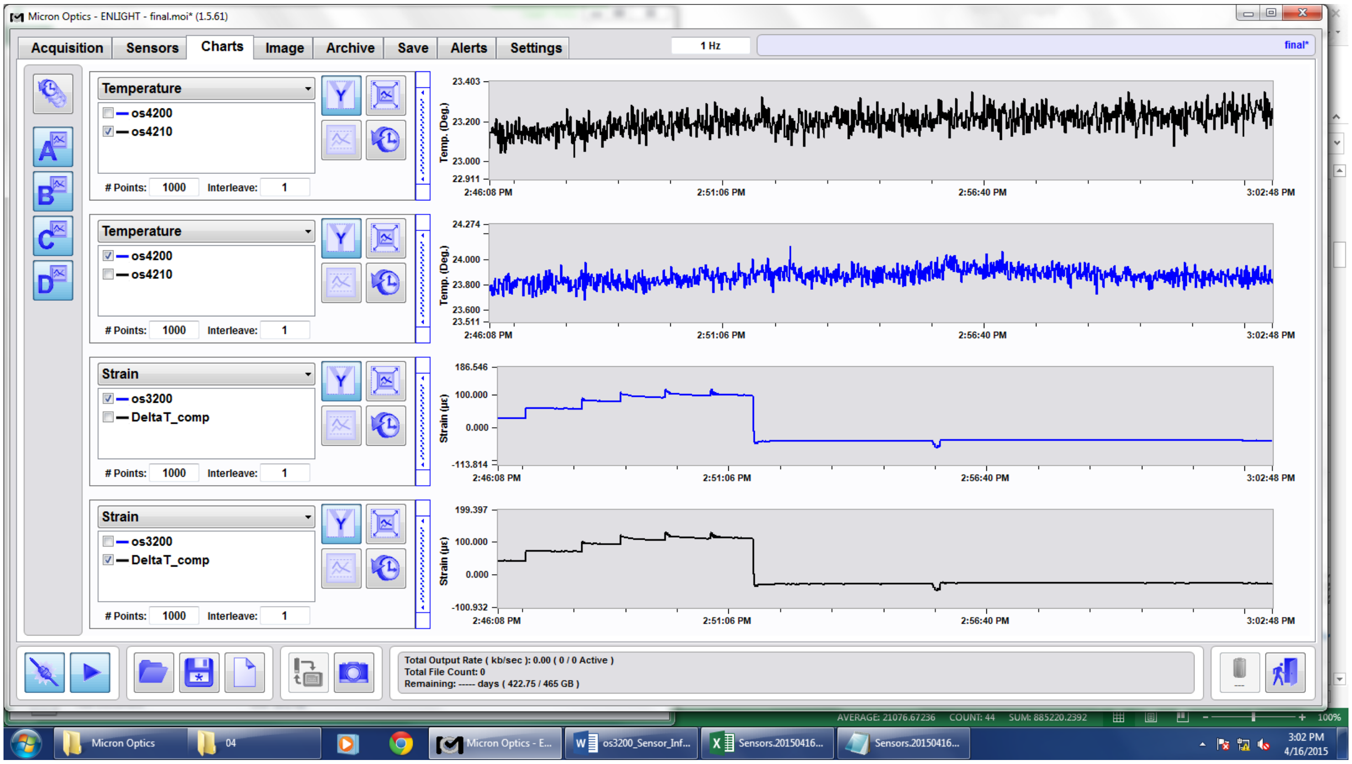


FIG. 6. *The Charts Tab* The charts tab of the Enlight software is shown here.

B. Experiment

1. *Experiment 1*

Zero your strain sensor while the bar is resting on the table. Now put your system in the initial configuration. Go to the save tab and set it to save all FBGs and sensors once per second. You must save your FBGs and sensors before starting, as they can't be edited while the save process is running. Start saving, and take data for one minute. Then add 100g and wait another minute. Continue adding weight and waiting until the desired maximum rate is achieved. Do not put more than 1 kg on the bar. When this is complete, stop the save process. Results shown in figure 7

2. *Experiment 2*

Zero the sensor in the resting position. Now put the bar on the drawers so that the strain sensor is on the side facing the ceiling. Start saving, and alternately add weight and wait just as before. Stop saving. Results shown in figure 8

3. *Experiment 3*

Now put the bar in the freezer for ∼20 minutes. Take it out and zero the strain sensor on the table. Put it on the drawer in the initial configuration. put on 100g, then start saving. Now let it take data for ∼30 minutes, or until the bar is nearly room temperature. This experiment will test your ability to compensate for the temperature. Results shown in figure 9

Appendix A: Appendices

1. Results and discussion

We made figures 7, 8, and 9 using the methods outlined in the experimental procedure section. They are plots of the mechanical strain vs time, obtained by plugging the experimental results into equation 16. Since we used electrical tape to affix the sensor to the bar instead of epoxy, our results are not guaranteed to be accurate.

In experiment 1 (figure 7) we see that the strain spikes with each addition of weight, and then decays with increasing effect as more weight is added. Our results seem to be reasonably accurate only up to 200g. If future attampts at this experiment do not use epoxy, then they should be conducted using smaller quantizations of mass (e.g. 10g)

In experiment 2, (figure 8), we see a similar effect, ex-

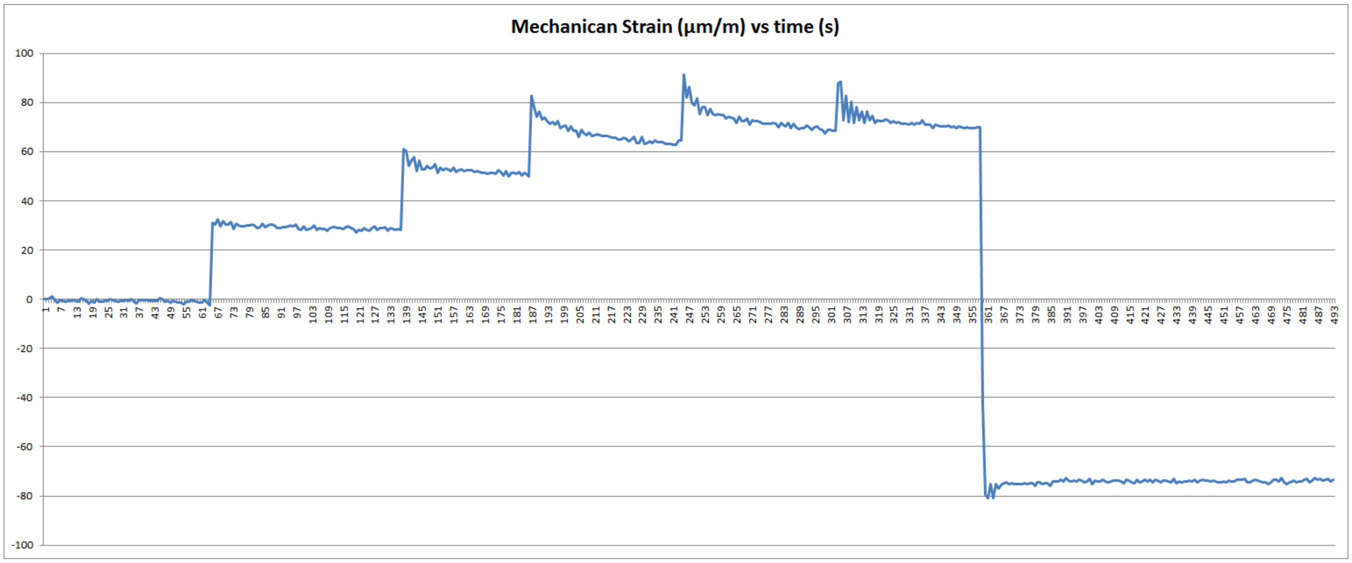


FIG. 7. Experiment 1: Isothermal measurement of the tension of the bottom of the bar.

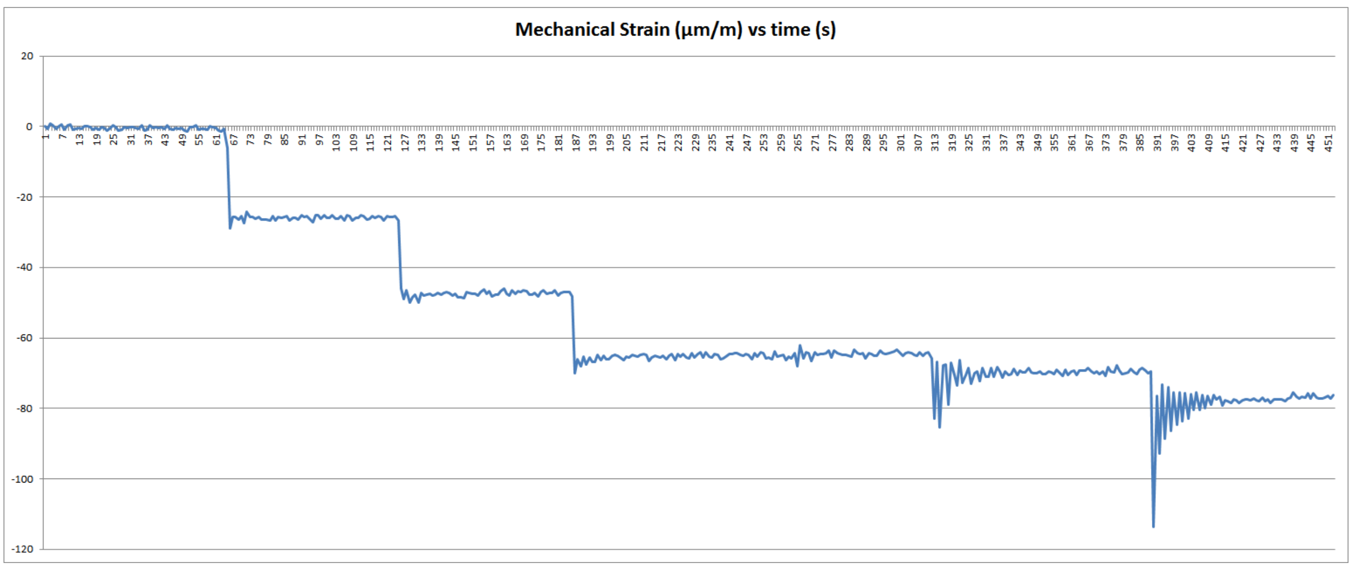


FIG. 8. Experiment 2: Isothermal measurement of the compression of the top of the bar

cept that it seems to be reasonably accurate up to 300g. This tells us that the tape has a greater ability to withstand compression than it does tension.

In experiment 3, (figure 9),there were many spikes in strain during the first half of the trial, and it smoothed out for the second half. This could mean that the tape is stronger at higher temperatures. Since the strain should be constant throughout this trial, this shows us that the tape is not adequate to hold the sensor to the bar if accurate results are desired.

[1] Wikipedia, "Fiber bragg grating," retrieved April 20, 2015 from http://en.wikipedia.org/wiki/Fiber_Bragg_grating (2015).

[2] Manfred Kreuzer, *Strain Measurement with Fiber Bragg Grating Sensors*, Tech. Rep. (HBM).

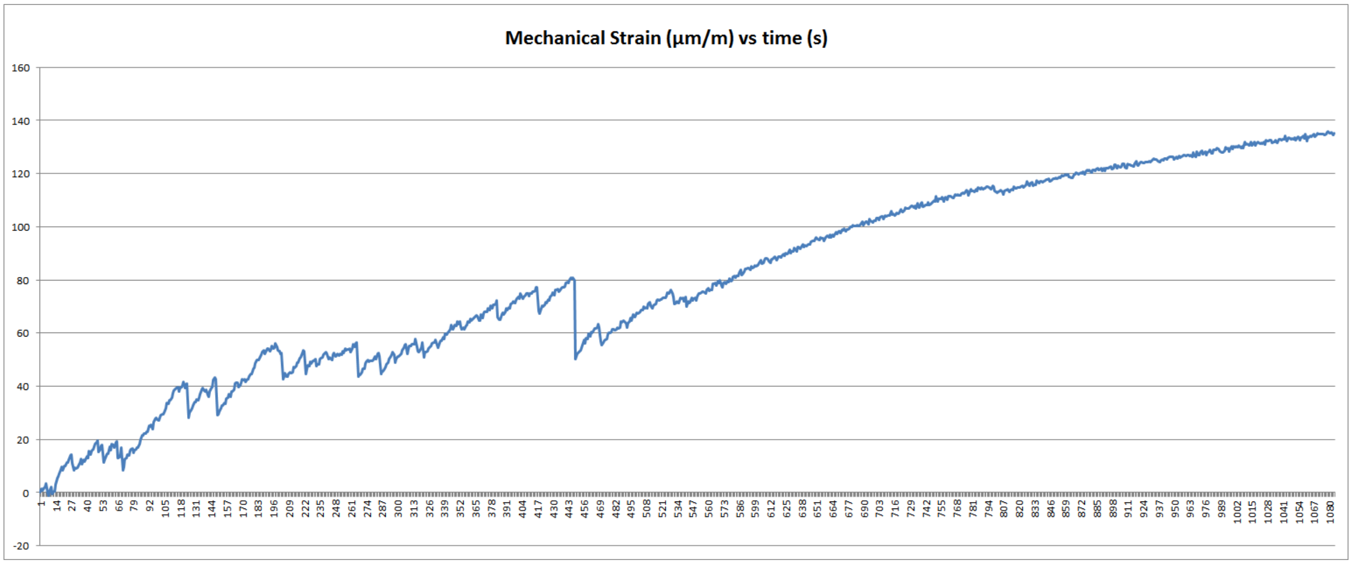


FIG. 9. Experiment 3: Thermally varying measurement of the tension of the bottom of the bar

Sensor Information Sheet

os3200 | Non-Metallic Optical Strain Gage

Part # os3200-wwww-1xx-1yy

Serial #

Nominal Wavelength, λ_0 (nm) @22°C 0000.0

Certified by: ________________

Variable	Description	Value	Units
F_G	Gage Factor	0.796 @ 22°C	-
C_1	Gage Constant 1	6.156 @ 22°C	μm/m-°C
C_2	Gage Constant 2	0.70	μm/m-°C
ΔT	Temperature Change	Measured	°C
CTE_S	CTE of Test Specimen	User Defined	μm/m-°C
$\Delta\lambda$	Wavelength Shift	Interrogated	nm
λ_0	Nominal Wavelength	Initial Value	nm

Strain (mechanically induced μm/m):

$$\varepsilon = (\Delta\lambda/\lambda_0)\ 1\text{x}10^6 / F_G - \varepsilon_{TO}$$

Thermal Output (thermally induced apparent strain, μm/m):

$$\varepsilon_{TO} = \Delta T\ [C_1 / F_G + CTE_S - C_2]$$

Thermal Output and Temperature Compensation

Fiber Bragg grating (FBG) based strain gages respond to both strain and temperature. Temperature induced strain results from a combination of two factors.

1) Thermal expansion of the substrate on which the gage is mounted.

2) Thermally induced index of refraction changes in the FBG.

Both factors affect the FBG's center wavelength.

Several methods are available to decouple strain and temperature components in measurements using this gage. Popular methods involve using FBGs to measure change in temperature or employing dummy FBG strain gages (as with conventional electronic strain gages).

For additional information about temperature compensation techniques and converting wavelength values to strain and temperature, see*:*

http://www.micronoptics.com/support_downloads/Sensors/

Micron Optics Quality and Performance

Products displaying the "Micron Optics Tuned" logo include Micron Optics tunable technologies thus ensuring high quality and performance. Certified sensors have been tested and qualified for use with Micron Optics Sensing Instruments.

Qualification Statement

This sensor has been manufactured using procedures and materials documented under Micron Optics, Inc's ISO 9001:2000 qualification process. This Sensor Information Sheet is verification of conformance.

Patent Certification

Micron Optics sensors and sensor interrogation instruments are covered under a US and International Patent Licensing Agreement between Micron Optics, Inc. and United Technologies Corporation. This license transfers to the users of Micron Optics sensor products and ensures that Micron Optics products are authorized for use in sensing applications. Certificates are available upon request.

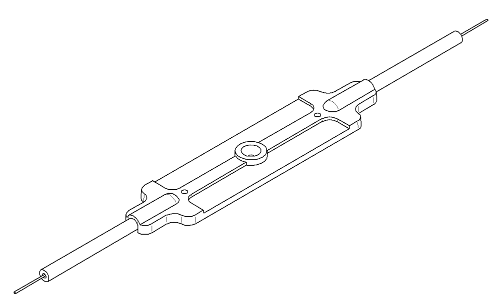
Installation Information

A os3200 gage may be bonded to a variety of surfaces. Successful installation requires careful attention to the details of gage installation. In particular, surface preparation and cleaning is extremely important in obtaining a secure bond.

The recommended adhesive for bonding os3200 gages to a specimen is a Loctite® Hysol® 1C-LV epoxy. This epoxy is available in an easy to use 50ml EPS Cartridge. Although it is possible to install gage with other adhesives, all performance data was obtained from gages installed with this epoxy.

The os3200 is qualified for dry environments. Installation instructions are available at:

http://www.micronoptics.com/support_downloads/Sensors/



MICRON OPTICS

1852 Century Place NE
Atlanta, GA 30345 USA
phone 404 325 0005
fax 404 325 4082
www.micronoptics.com

Certificate of Calibration

Description: Optical Temperature Sensor - Metallic		Pigtail Configuration: Single Ended
		Termination: None
Model No.	os4200	Options:
Serial No.	B222563	As-Found Condition: New
Wavelength:	1524	As-Left Condition: Calibrated
Calibration Range:	-40°C to 120°C	Calibration Procedure

The above grating based optical temperature sensor has been calibrated using the following equipment. A Micron Optics Inc. sm125 optical sensing interrogator with a NIST traceable gas cell for a reference, was use to record the sensor wavelength. The accuracy and repeatability of this instrument is as follows:

Parameter	Value
Accuracy	1 pm
Stability	1 pm
Repeatability	0.5 pm
Wavelength range	1510 – 1590 nm

Temperature response was recorded from a platinum resistance thermometer with a digital readout and is calibrated annually per the manufacturer's recommendations and is traceable to NIST standards. The system has the following characteristics:

Parameter	Value
Temperature Range	-200°C to 300°C
Accuracy (estimated combined)	±0.05°C
Short Term Repeatability	±0.013°C @ 0.010°C

Environmental conditions of the laboratory are controlled at 22°C ±4°C and 70% maximum relative humidity.

The following temperature coefficients were obtained using a temperature controlled chamber to record both wavelength and temperature of the optical sensor by monitoring many discrete points over the entire temperature range and fitting a polynomial to the resultant data.

$$T = C_3*WL^3 + C_2*WL^2 + C_1*WL+C_0$$

Where: T – Temperature in degrees C
WL – Wavelength in nanometers

Constant	Value
C_3	3.9818360927238200
C_2	- 18220.205861071700
C_1	+ 27790944.820601500
C_0	- 14129717267.625100

Calibration performed and approved by:

________________________________ Date of Issue 10/13/08

MICRON OPTICS

1852 Century Place NE
Atlanta, GA 30345 USA
phone 404 325 0005
fax 404 325 4082
www.micronoptics.com

Certificate of Calibration

Description: Optical Temperature Sensor - Metallic		Pigtail Configuration: Single Ended Termination: None
Model No.	os4200	Options:
Serial No.	B222536	As-Found Condition: New
Wavelength:	1536	As-Left Condition: Calibrated
Calibration Range:	-40°C to 120°C	Calibration Procedure

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$$T = C_3 * WL^3 + C_2 * WL^2 + C_1 * WL + C_0$$

Where: T – Temperature in degrees C
WL – Wavelength in nanometers

Constant	Value
C_3	3.9317263733300900
C_2	- 18131.653123071000
C_1	+ 27872224.757467100
C_0	- 14281899803.880900

Calibration performed and approved by:

______________________________ Date of Issue 10/13/08

Micron Optics, Inc.
os3200 Strain Gage
Installation Procedure

Figure 1 – os3200 Strain Gage

Introduction:

An os3200 gage may be bonded to a variety of surfaces using the procedure outlined below. Successful installation requires careful attention to the details of gage installation. In particular, surface preparation and cleaning is extremely important in obtaining a secure bond.

The recommended adhesive for bonding os3200 gages to a specimen is a Loctite® Hysol® 1C-LV epoxy. This epoxy is available in an easy to use 50ml EPS Cartridge. Although it is possible to install gage with other adhesives, all performance data was obtained from gages installed with this epoxy.

1. Supplies

The following supplies are required for successful installation of the os3200 Strain Gage:

Loctite® Hysol® 1C-LV, 50ml EPS Cartridge (Loctite 83208)
Dual Cartridge Manual Applicator, 2:1 (Loctite 98472)
Mix Nozzle (Loctite 98455)
3ml Syringe with Luer-Lok™ Tip (BD 309585)
Dispenser Tip (EFD 5120TT-B)
CRC Industrial Super Degreaser (No. 03110)

2. Gage Preparation

The gage comes from the factory ready to install on the specimen. No gage preparation is required prior to installation. The gage has an adhesive pre applied to the bottom surface of the gage. The adhesive is covered with a protective backing. Do not remove the protective backing until the specimen surface has been properly prepared and you are ready to install the gage.

3. Surface Preparation

3.1. Prep Surface

Mounting surface must be reasonably flat and free of surface defects. The surface should be free of rust, scale, oxides, loose paint, or other coatings. Start by degreasing the surface with CRC Degreaser or other degreaser compatible with the specimen. Abrade the surface as necessary to remove surface irregularities and contamination. It may be necessary to start with a coarse paper or grinder if the surface is very rough. Use consecutively finer paper finishing up with 400-grit silicon-carbide paper.

3.2. Pre-Position Gage

Use a spare or dummy gage to determine how the gage will be positioned on the specimen. Do not use the active gage or it will be contaminated with finger oil and contamination from the specimen surface. Note that the gage is sensitive to strains parallel to the axis of the fiber. Using a drafting pencil, burnish whatever alignment marks are necessary on the specimen for repositioning the gage.

3.3. Degrease

Thoroughly degrease mounting surface using CRC Degreaser. Isopropyl alcohol may be substituted for CRC if desired; however, it may not be as effective in removing all traces of contaminants. CRC Degreaser is preferred whenever possible. Apply a liberal amount of degreaser to the specimen surface and wipe dry with clean gauze. Repeat several times to thoroughly degrease surface.

4. Apply Gage

Remove protective backing from bottom surface of gage. Carefully position gage over test specimen and press firmly into place. If multiple gages are to be mounted in close proximity, wear latex gloves or cover gage with plastic film before pressing down on gage. This will prevent finger oil from contaminating the specimen. Gage should not be repositioned after it is in place.

5. Inject Epoxy

5.1. Prepare epoxy syringe

Place epoxy cartridge in proper dispenser. To begin using new cartridge, remove cap and dispense a small amount of adhesive, making sure both Part A and B are extruding. Attach nozzle and dispense approximately 1-2" to ensure that the mixing tip is filled with both resin and hardener. Remove plunger from 3ml Syringe and install dispenser tip on end of syringe. Insert tip of dispensing nozzle into the back of the syringe and inject epoxy into the syringe. Try to lay a bead of epoxy on the sidewall of the syringe. This will allow the air to be purged from the syringe. Insert plunger into syringe and press plunger to force air out of syringe. 1ml of epoxy is more than enough to install a handful of gages.

5.2. Inject epoxy

Wipe excess epoxy off of syringe dispenser tip. Insert dispenser tip into hole located in the center of the os3200 gage. Hold dispenser tip against gage with gentle pressure. It is not necessary to press hard. Excessive pressure may damage fiber Bragg grating. Press syringe plunger down to force epoxy into sensor. Continue to apply pressure to plunger until epoxy is visible at the two vent holes located at each end of sensor.

6. Cure

6.1. In order to minimize residual stresses within the cured epoxy, it is recommended to allow the epoxy to cure at room temperature 70°F to 80°F [20°C to 30°C].