INSTRUCTION MANUAL

SENSOPTIC FIBER-OPTIC SENSORS

FABRY PEROT STRAIN GAUGE

FOS Series

This product should be installed and operated only by qualified personnel. Its misuse is potentially dangerous. The Company makes no warranty as to the information furnished in this manual and assumes no liability for damages resulting from the installation or use of this product. The information herein is subject to change without notification.

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1 PRODUCT

1.1 INTRODUCTION

The SENSOPTIC line of fiber optic sensors are specially developed instruments that can be used in a variety of applications where their small size, high accuracy, broad measurement range and complete immunity to EMI / RFI / Lightning are of paramount importance. In addition, they have an excellent dynamic response, which allows combined static and dynamic measurements, according to the specific needs of the investigated structure.

The FOS can be surface-mounted on a variety of materials including steel, concrete and composite materials using suitable industrial quality adhesives. The gauge is intended for long-term, precise strain measurements and can be read by all ROCTEST's fiber-optic readout units which displays readings directly in units of microstrains (see separate instruction manual for operation of the readout unit).

1.2 DESCRIPTION

The gauge, namely a Fabry-Perot strain gauge, is based on a white-light interferometric extrinsic principle that uses a common multimode fiber.

The patented* principle consists in assessing the length of a Fabry-Perot cavity contained in the strain gauge by means of a Fizeau interferometer located in the readout unit, that optically reproduces the length of the Fabry-Perot cavity and allows to digitize that length on a high density linear photodiode array attached along one side of the interferometer (Figure 1).

The Fabry-Perot cavity is made of two 125 microns diameter fibers facing each other and fused in a 200 microns diameter glass micro-capillary, with a semi-reflective mirror coating on each fiber's tip. Then, the strain variations transferred to the gauge are converted into cavity length variations.

The length of the Fabry-Perot cavity, as compared to the distance between the fused welding spots on the fibers, defines the range of the strain gauge, whereas the sensitivity of the gauge is defined by the density of the photodiode array used in the readout unit.

The **FOS-B** model consists of an **FOS** sensor embedded in a composite material blade ready to be bonded to concrete and other surfaces.

* U.S. Patent 5,202,939

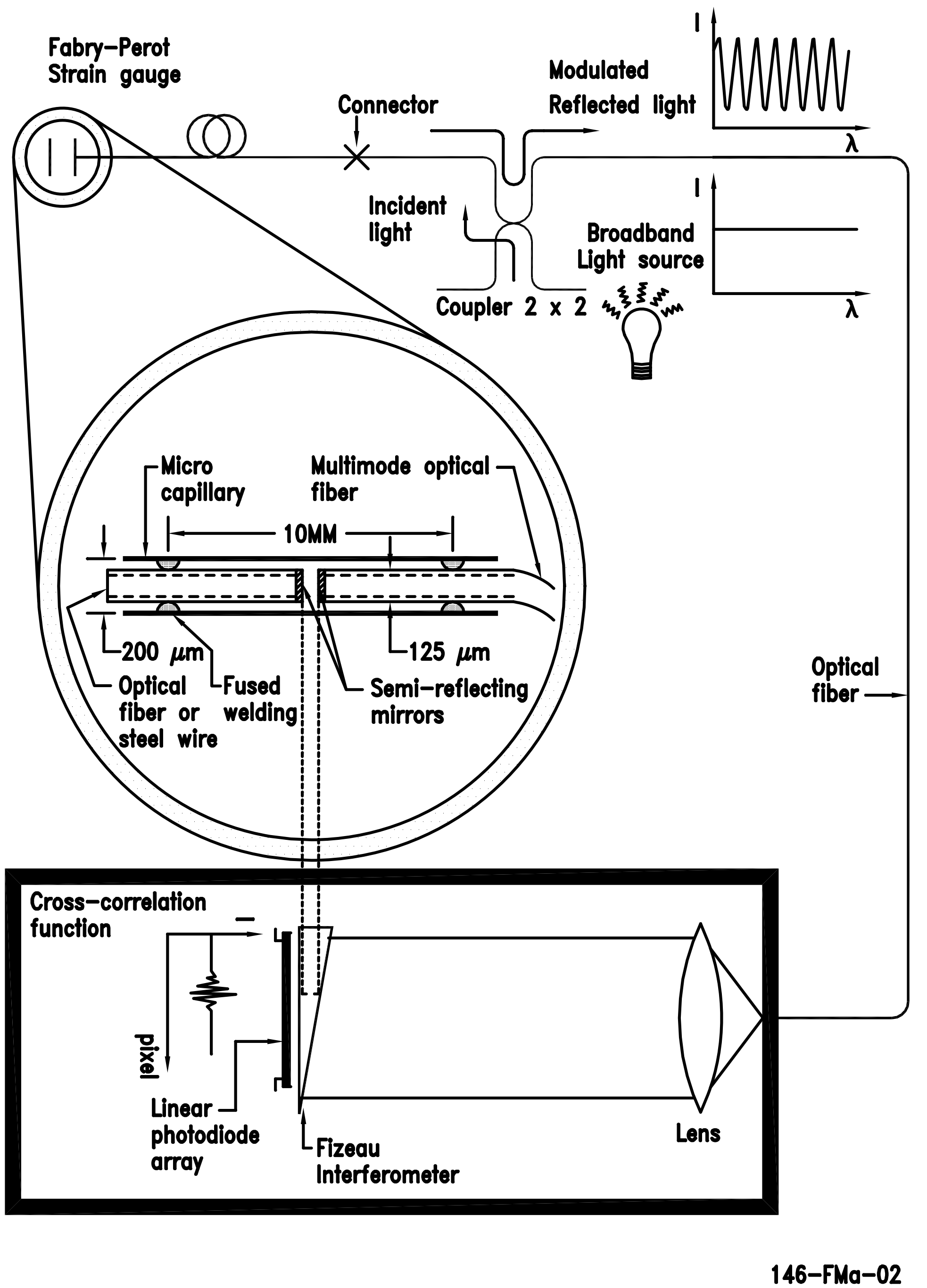


Figure 1 Fabry-Perot strain gauge schematic principle

1.3 SPECIFICATIONS

Gauge type:	**FOS:** Standard fiber-optic strain gauge **FOS-N:** Non temperature compensated FOS **FOS-C:** Temperature compensated FOS **FOS-B:** FOS encapsulated in a blade **FOS-R:** FOS encapsulated in a rod
Stain range (microstrains):	±1 000, ±2 000, ±3 000, ±5 000 0 to 2 000, 0 to 3 000, 0 to 5 000 minus 2 000 to 0, minus 3 000 to 0, minus 5 000 to 0, (other available on request)
Resolution:	0.01% of full scale
Precision:	Range dependent
Transverse sensitivity:	<0.1% of full scale
Response time:	Readout unit/data logger dependent
Operating temperature:	Minus 55°C to +350°C; operating temperature is fiber-optic cable dependent
EMI/RFI susceptibility:	Intrinsic immunity
Combatibility::	All ROCTEST's fiber-optic readout units and data loggers
Cable length:	1.5 meter length. Custom length up to 5 km available
Gauge dimensions:	310 microns diameter
Fiber-Optic Cable:	4.0 mm O.D. polyurethane jacket Kevlar™ reinforced (minus 55°C to +85°C), or 1 mm O.D. braided fiberglass cable (minus 55°C to +350°C)
Gauge material:	Glass
Connector:	ST Connector

2 INSTALLATION

2.1 GAUGE INSTALLATION

The steps for bonding the fiber optic strain gauges depend upon the adhesive used. Epoxy and ceramic adhesives and even metal arc spraying can be used to bond gauges. As with conventional strain gauges, high residual compression strains occur when adhesives are heat cured at elevated temperatures. When gauges adhere to the pieces at elevated temperatures, compressive strains are generated in the gauges as the pieces cool down. Residual compression strains can be controlled by curing adhesives while the pieces are put into tension prior to cooling, or consideration may be given to this behavior while ordering the gauges. Contact the Manufacturer for information.

The Manufacturer suggests using the M-BOND AE-10 or AE-15 epoxy adhesives from MEASUREMENTS GROUP (Micro-Measurements Division) for low temperature applications (up to 95°C). For high temperature applications, the use of M-BOND 600 (up to 370°C short term and 260°C long term) is recommended. Mixing instructions and adhesive characteristics are given by the adhesive manufacturer. Slowly mixing the resin and hardener is recommended to prevent excessive amount of air (bubbles). The basic steps for bonding strain gauges with AE-10 or AE-15 epoxy from Micro-Measurements are given in the next paragraphs. Remember: the key for successful bonding of strain gauges is to have a good contact between the gauge and the specimen to be measured. Here are some accessories and products that you will need for installation of the FOS strain gauge:

- CSM-1A Degreaser (from Measurements Group) or Isopropyl Alcohol;
- MJG-2 Mylar Tape (from Measurements Group) or "Scotch" Tape;
- M-Prep Conditioner A (from Measurements Group) or mild phosphoric acid compound (10% concentration in distilled water);
- M-Prep Neutralizer 5A (from Measurements Group) or ammonia-based neutralizer compound made of isopropanol (15% conc.), Ammonium Hydroxide (5% conc.), and Distilled Water (80% conc.);
- Five Minute type epoxy;
- Mylar or high temperature adhesive tape such as Teflon or Kapton adhesive tape;
- Silicon-Carbide Abrading Paper (Grit 220 or 320 and grit 400);
- Low lint wipers (Kimwipes wipers);

- Cotton tipped applicators (Cotton Swabs);
- Waterproof tape (Aquaseal);
- Nitrile and butyl rubber sealants;
- M-Coat Protective Coating (from Measurements Group) - Optional.

Note: The manufacturer can provide a complete Gauge Installation Kit which includes the adhesive with all the accessories and products mentioned above. For more information, please contact the manufacturer.

HANDLING PRECAUTIONS: *Epoxy resins and hardeners may cause dermatitis or other allergic reactions, particularly in sensitive persons. The user is cautioned to:* ***(1)*** *avoid contact with either the resin or hardener;* ***(2)*** *avoid prolonged or repeated breathing of the vapors; and* ***(3)*** *use these materials only in well-ventilated areas. If skin contact occurs, thoroughly wash the contaminated area with soap and water immediately. In case of eye contact, flush immediately and secure medical attention. Rubber gloves and aprons are recommended, and care should be taken not to contaminate working surfaces, tools, container handles, etc. Spills should be cleaned up immediately.*

2.1.1 METAL SURFACE PREPARATION

The surface preparation technique is the same basic procedure as for conventional strain gauges. The initial step is to clean the surface in order to remove oil, grease, organic contaminants and chemical residues. Solvents such as CSM-1A from MEASUREMENTS GROUP (Micro-Measurements Division) or GC-6 Isopropyl Alcohol or solvent 755 from Loctite can be used. The substitution of Isopropyl Alcohol as a degreasing agent should be considered for materials that may be sensitive to strong solvents. Any degreasing should be done with clean solvents. Thus the use of a "one-way" container, such as the aerosol can, is highly advisable.

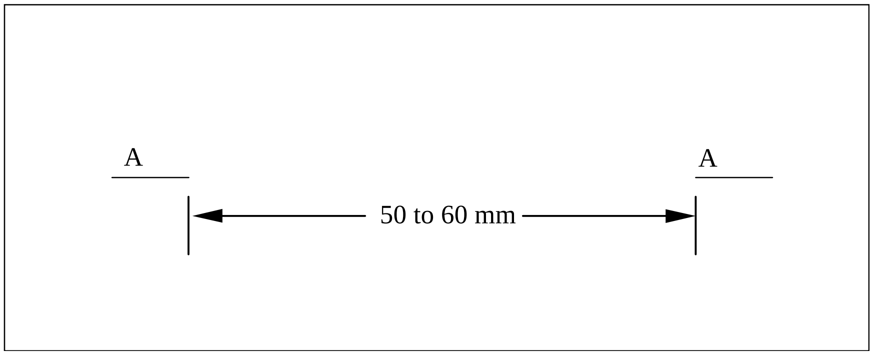
Next, the surface must be abraded to remove any loosely bonded adherents like scale, rust or paint. Dry-abrade the gauge area with silicon-carbide paper of the appropriate grit (generally 220 or 320). For rough or coarse surfaces, a grinder or file can be used to start abrading. Apply M-Prep Conditioner A (or the equivalent compound) and wet-abrade the gauge area. Keep the surface wet while abrading. Remove the residue and Conditioner by slowly wiping through the gauge area with clean low lint wipers

(Kimwipes wipers). The wet-abrade and wiping procedure should then be repeated with 400-grit silicon-carbide paper. Rewet the surface with Conditioner A (or the equivalent compound) and scrub with cotton tipped applicators until a clean applicator is no longer discolored by the scrubbing. Remove the residue and Conditioner by slowly wiping through the gauge area with clean Kimwipes.

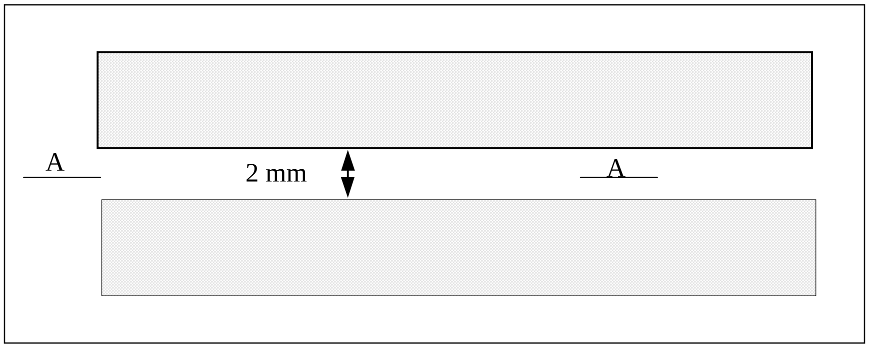
The final step is to apply a liberal amount of M-Prep Neutralizer 5A from Micro-Measurements to the gauge area. Keeping the surface wet, scrub with cotton tipped applicators. Do not allow evaporation of the cleaning material since this would leave a thin, unwanted film between the adhesive and the surface. Remove the neutralizer by slowly wiping through the gauge area, allowing the clean Kimwipes to absorb the Neutralizer. **Do not wipe back and forth over the gauge area since this may allow contaminants to be redeposited on the cleaned area.**

2.1.2 BONDING METHOD

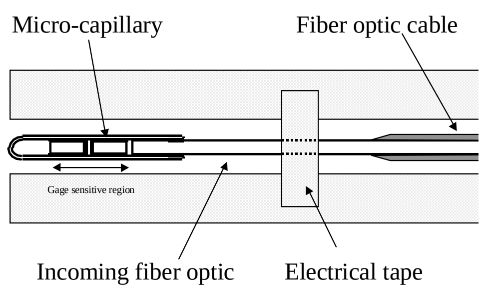
A) With a lead pencil, make two marks (A) along the projected bond line, approximately 50 to 60 mm apart.



B) With a flashbreaker or an electrical tape, create a channel into which the fiber sensor will be installed. The width of this channel must be approximately 2 mm.

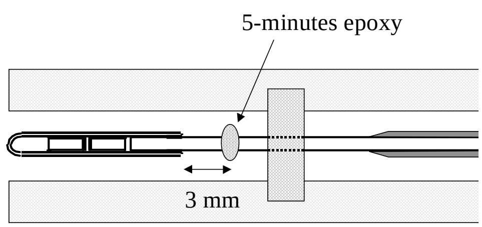


C) Place the gauge between the channel of electrical tape and hold it in place by applying tape ("scotch" tape may also be used) on the incoming fiber-optic 25 mm away from the micro-capillary. Position the gauge on the surface and tack the tape to maintain proper alignment. The sensitive area is collinear to the axis of the fiber. The location of the sensitive area of the gauge is shown on the box cover that contain the fiber-optic gauge.



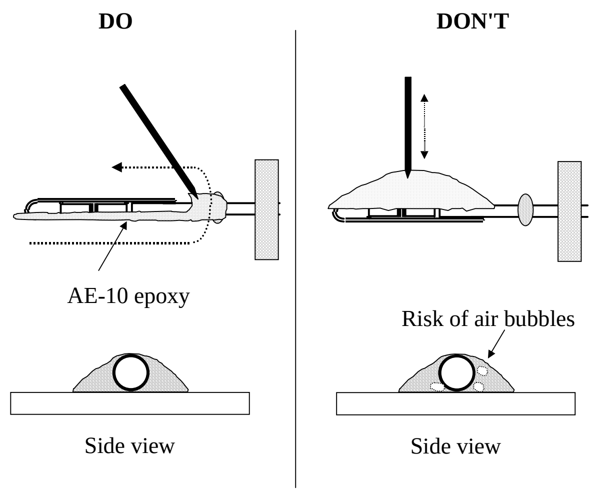
Note: The gauge micro-capillary is made of glass and doesn't have any protective coating so it should be handled with care prior to bonding the gauge. Any scratches made to the glass micro-capillary may impair the efficiency and the lifetime of the gauge.

D) The incoming optical fiber must be secured on the specimen with a very small drop (less than 1 mm) of 5-minutes epoxy about 3 mm away from the micro capillary. To ensure that the 5-minutes epoxy will not flow to the micro-capillary, we recommend letting the epoxy cure slightly before applying it on the fiber in order to increase viscosity.

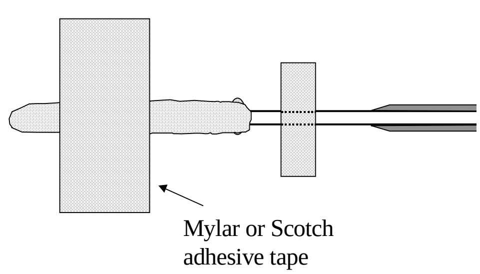


Reminder: To avoid surface contamination, do not touch the micro-capillary of the Fiber-Optic Strain Gauge with your hands. The gauge micro-capillary must be free of grease, dust, etc. If necessary, use a Duster can or clean dry air to blow away dust, dirt and grit on the micro-capillary.

E) Once the 5-minutes epoxy is cured, mix the adhesive by following the mixing instructions of the adhesive manufacturer. Slowly mix the resin and hardener to prevent excessive amount of air bubbles using a clean stick (or brush) and apply the adhesive slowly with a linear motion parallel to the gauge orientation. Make sure the entire gauge is covered from the tip to the 5-minutes epoxy.

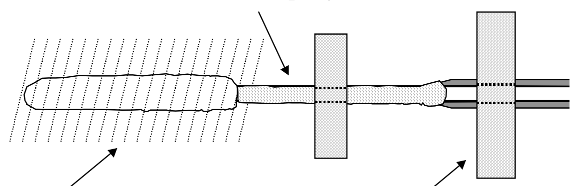


F) Immediately after applying the adhesive, a Mylar or high temperature adhesive tape (a "scotch" tape may also be used if curing temperature is low) may be installed over the adhesive in the gauge sensitive region in order to keep the gauge in good contact with the specimen. Do not apply excessive pressure over the micro-capillary while applying the tape (this tape is removed after curing). Follow the recommended cure schedule given by the adhesive manufacturer. Note that the residual compression strain may increase with increasing curing temperature. Post-curing the installation for two hours at least 158C above the maximum operating temperature with all tapes removed will provide essentially creep-free performance.

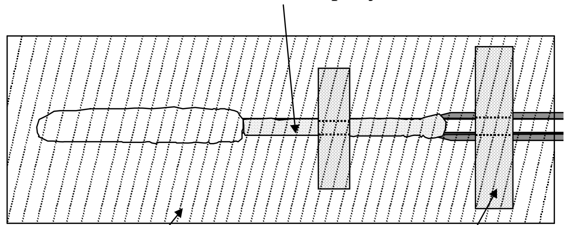


Reminder: The key for successful strain gauge bounding is to have a good contact between the gauge and the specimen to measure.

G) After curing you may apply 5-minutes epoxy (if the gauge is used at low temperature) over the remaining unprotected optical fiber up to the fiber jacket. Then use electrical tape to attach the fiber-optic cable to the structure. You may also apply a protective coating like the M-Coat Protective Coating (from Measurements Group) over the adhesive for improved protection against chemical attack, moisture, etc. Let dry for a few minutes.



H) As mechanical protection waterproofing tape (Aquaseal) or nitrile rubber sealant and butyl rubber sheets can be used. The area to be covered by the protective coating is illustrated below. When applying the coating onto the surface of the installation, be careful to use a light amount of pressure on the sensor area. Carefully apply moderate pressure on both sides of the optical fiber and press firmly toward the edges to have proper bonding with the surface. The perimeter of the coating installation can be sealed with a sealing material such as silicone. Finally, use electrical tape to attach the fiber-optic cable to the structure beyond the sensor area to avoid any effect on the sensor itself.



2.1.3 REBAR INSTALLATION

To install instrumented rebar into a new structure as part of the reinforcement cage, a portion of the surface of rebar 70-80 mm long should be milled flat. This forms a perfect surface on which to bond a sensor and the installation procedure is the same as described in section 2.1.2.

2.1.4 INSTALLATION OF SENSORS WITH COMPOSITE LAMINATES ON CONCRETE STRUCTURES

The FOS or FOS-B fiber-optic sensor can be installed on existing concrete structures using composite laminate overwraps. For example, carbon or glass fiber reinforced polymer (CFRP or GFRP) can be used as a protective wrap that also strengthens the structure. This type of installation can be done according to the following steps.

1. Surface preparation
2. Primer application
3. Putty application
4. Epoxy application
5. CFRP/GFRP bottom sheets installation
6. Epoxy application and FOS/FOS-B installation
7. CFRP/GFRP top sheets installation (optional)
8. Final epoxy coating
9. Curing

1. Surface preparation
   - Concrete surface must be sanded smooth to the touch
   - Wash the sanded surface with water using a stiff bristle brush
   - Let dry for 24 hours, then brush the surface again and spray with an air hose
   - Make sure that the concrete surface is dry

NOTE: ***When applying primer, putty or epoxy, always follow manufacturer's instructions as to:***

- Wearing a protective mask, goggles or gloves
- Mixing procedure;
- Applying procedure
- Curing time

In each case, always make sure that:

- No (or few) air bubbles have been formed during mixing
- The surface is clean and dry prior to application

2. Primer application

A primer should be applied in order to increase the strength of concrete surface and improve bounding. Different types of primers can be used (CAPHARD E30, EPOTHERM, …).

3. Putty application

If the concrete surface has not been sanded, it is recommended to apply putty to smooth pores and gaps on the concrete surface. Any gap larger than 1 mm should be eliminated.

4. Epoxy application

The use of epoxy is necessary in order to secure the composite laminate overwraps and the sensor to the concrete. Prior to mixing the epoxy, cut all sheets of laminates to size. Apply the epoxy uniformly to the surface of concrete. The coating quantity of undercoating varies depending on the type of epoxy, the surface condition of concrete and type of CFRP/GFRP. The standard coating quantity is 400 - 500 g/m^2. The coating must be applied uniformly. Insufficient application may cause troubles of swelling or floating of the CFRP/GFRP sheet. More epoxy must be applied to internal angles than for flat surface.

5. CFRP/GFRP bottom sheets installation

- When handling of CFRP/GFRP sheets, wear a pair of protective goggles and gloves
- Immediately after epoxy application, install the layer of CFRP/GFRP sheets
- Place the sheet with the meshed surface (surface with a backing paper attached) located outside.
- Stick it and smooth by hand so that no air remains between the sheet and the concrete. Be careful to avoid loosening, wrinkles or fraying of the fibers.
- Peel away the backing paper.
- Squeeze the sheet rather strongly with a roller or a brush in order to impregnate the epoxy into the fiber and remove any entrapped air. Proceed in fiber longitudinal (**and not transversal**) direction. A 20 cm overlapping is required when two sheets are connected in the fiber longitudinal direction.
- After placing a CFRP/GFRP layer, wait one hour in order to let the epoxy impregnate the sheets.

6. Epoxy application and FOS/FOS-B Installation

The FOS/FOS-B sensor must be bonded onto the CFRP/GFRP sheet at the proper location. The sensor and the fiber optic cable must be placed parallel to the fiber to avoid the creation of bump. Next, apply epoxy over the sensor, the cable, and to the entire surface of the CFRP/GFRP layer. Follow instructions above.

The user should note that the FOS-B can also be bonded directly on concrete or on a CFRP/GFRP sheet, and then simply covered with a coat of epoxy.

7. CFRP/GFRP top sheet installation (optional)

In option, additional layer(s) of CFRP/GFRP can be installed. In such case, install the additional layer of pre-cut sheets such a way that fibers on the latter are perpendicular to the fiber of the bottom sheets. Follow instructions above. Brush or roller must be used in fiber longitudinal direction. In order to avoid the disalignment of fiber or peeling off of the mesh, do not stroke brush or roller on to the sheet strongly.

8. Final epoxy coating

The last layer of CFRP/GFRP must be covered with an over-coating of epoxy of approximately 200-300 g/m^2. Follow instructions above.

9. Curing

Let cure. The work site must be protected from rain, dust, sand, etc.

2.2 MATING GAUGES TO THE READOUT UNIT

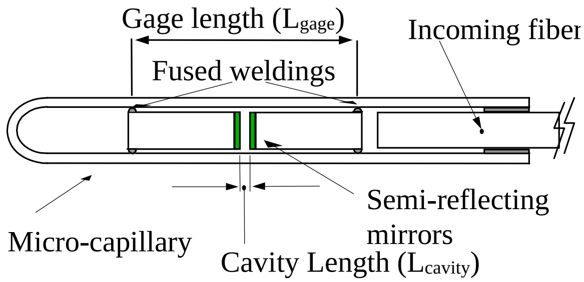
Before installing and using the gauge, the readout unit manual must be read and understood.

For proper use of the fiber optic strain gauges, the gauge fiber optic connector must be kept clean and free of dust at all times. Dust may obstruct the light transmitted from one connector to the other, and reduce the signal-to-noise ratio to an unusable level. These connectors can be cleaned with the Fiber Optic Connector Cleaning kit, and it is a good practice to always clean the gauge connector before mating to the instrument. Gauge connectors can be cleaned by wiping the end with soft tissues such as Kimwipes. The input connectors of ROCTEST's fiber-optic readouts unit must be clean as well. Use the specially designed 2.5 mm mini foam swab for cleaning the input connectors of your readout unit.

3 DATA READINGS AND ANALYSIS

Method for interpreting readings with the FOS Fabry-Perot strain gauge

The following method is proposed as a tool for properly interpreting readings but the manufacturer should in no way be considered responsible if results obtained do not meet expectations.



Relation between the length of the cavity (L_{cavity}) and the strain (ε) is determined by the following formula:

$$\varepsilon = \frac{\Delta L}{L_{gage}} = \frac{(L_{cavity} - L_o)}{L_{gage}} \qquad \textbf{(1)}$$

where:

L_{cavity}	=	Length of the Fabry-Perot cavity, in nanometers (varies between 8 000 and 23 000 nm)
L_{gage}	=	Gauge length (space between the fused weldings), in millimeters
L_0	=	Initial length of the Fabry-Perot cavity, in nanometers
ε	=	Total strain measurement, in μstrains

<u>Total strain ε</u>

Total strain ε is the raw strain obtained directly from FOS readings with all ROCTEST's fiber-optic readout units after the gauge factor has been defined in readout memory and selected.

$$\varepsilon = \varepsilon_1 - \varepsilon_0 \qquad \textbf{(2)}$$

where:	ε	=	Total strain measurement, in µstrains
	ε_1	=	Current strain, in µstrains
	ε_0	=	Initial strain, in µstrains

This total strain includes the mechanical strains and thermal strains in the investigated structure. The method detailed below explain how to obtain the mechanical strain due to applied effective stress.

The real strain ε_r (due to applied effective stress) can be computed with the following formula:

$$\varepsilon_r = \varepsilon - \beta \cdot (T_1 - T_0) \qquad \textbf{(3)}$$

Where:	ε_r	=	Real strain, in µstrains
	ε	=	Total strain reading, in µstrains
	T_1	=	Temperature reading of structure, in °C
	T_0	=	Initial temperature reading of structure, in °C
	β	=	Expansion factor of structure in µm/m/°C on which the gauge is fixed, generally in the range of 10 µm/m/°C < β < 16 µm/m/°C for steel. The β expansion factor can be known from laboratory test.

Numerical example:

ε_0	=	2200.2 units, initial reading of FOS with the ROCTEST's fiber-optic readout unit
ε_1	=	2407.8 units, current reading of FOS with ROCTEST's fiber-optic readout unit
T_0	=	20.2°C, initial temperature reading
T_1	=	26.2°C, current temperature reading
β	=	12.0 µm/m/°C, structure expansion factor

First the total strain (ε) must be found:

$$\varepsilon = \varepsilon_1 - \varepsilon_0 = 2407.8 - 2200.2 = 207.6 \text{ microstrains}$$

Therefore the real strain ε_r is:

$$\varepsilon_r = \varepsilon - \beta \cdot (T_1 - T_0)$$

$$\varepsilon_r = (207.6) - 12 \cdot (26.2 - 20.2) = 135.6 \text{ microstrains}$$

Note: Positive values of ε_r represent tensile strains and negative values represent compressive strains.

4 MISCELLANEOUS

4.1 CONVERSION FACTORS

	To Convert From	To	Multiply By
LENGTH	Microns Millimiters Meters	Inches Inches Feet	3.94E-05 0.0394 3.2808
AREA	Square millimiters Square meters	Square inches Square feet	0.0016 10.7643
VOLUME	Cubic centimeters Cubic meters Liters Liters	Cubic inches Cubic feet U.S. gallon Can–Br gallon	0.06101 35.3357 0.26420 0.21997
MASS	Kilograms Kilograms Kilograms	Pounds Short tons Long tons	2.20459 0.00110 0.00098
FORCE	Newtons Newtons Newtons	Pounds-force Kilograms-force Kips	0.22482 0.10197 0.00023
PRESSURE AND STRESS	Kilopascals Bars Inches head of water* Inches head of Hg Pascal Kilopascals Kilopascals Kilopascals	Psi Psi Psi PsI Newton / square meter Atmospheres Bars Meters head of water*	0.14503 14.4928 0.03606 0.49116 1 0.00987 0.01 0.10199
TEMPERATURE	Temp. in °F = (1.8 x Temp. in °C) + 32 Temp. in °C = (Temp. in °F – 32) / 1.8		

* at 4 °C

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Table 1: Conversion Factors