INSTRUCTION MANUAL

SENSOPTIC FIBER-OPTIC SENSORS

SPOT WELDABLE STRAIN GAUGE

Model SFO-W

Tel.: 1.450.465.1113 • 1.877.ROCTEST (Canada, USA) • 33.1.64.06.40.80 (France) • 41.91.610.1800 (Switzerland)

www.roctest-group.com

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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 (electromagnetic and radio frequency interferences) are of paramount importance. In addition, they have an excellent dynamic response, which opens the possibility of combined static and dynamic measurements, according to the specific needs of the investigated structure.

The SFO-W gauge is designed to be installed by a technician without the assistance of a skilled welder. The SFO-W gauge is intended for long-term, precise strain measurements on a variety of structures.

2 EQUIPMENT DESCRIPTION

2.1 DESCRIPTION OF FABRY-PEROT STRAIN GAUGE

The SFO-W sensor is based on a unique fiber-optic strain gauge which constitutes a breakthrough in fiber-optic sensing. 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 photo diode 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, since the Fabry-Perot strain gauge is assembled in the SFO-W sensor, the strain variations transferred to the gauge are converted into cavity length variations.

Alternatively, one of the fibers can be replaced by a thin metallic fiber having the same thermal expansion as the structural material to make a thermally compensated strain gauge (patented) as illustrated in figure 2. In this case, if the gauge is submitted to an elongation or compression which is due to thermal dilation, then the cavity length will not change because it is self-compensated by the metallic fiber moving in opposite direction. The position of the spots welding the metallic fiber on one side and the optical fiber on the other side is adjusted in factory to give the required thermal compensation.

The length of the Fabry-Perot cavity, as compared to the distance between the fused welding 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.

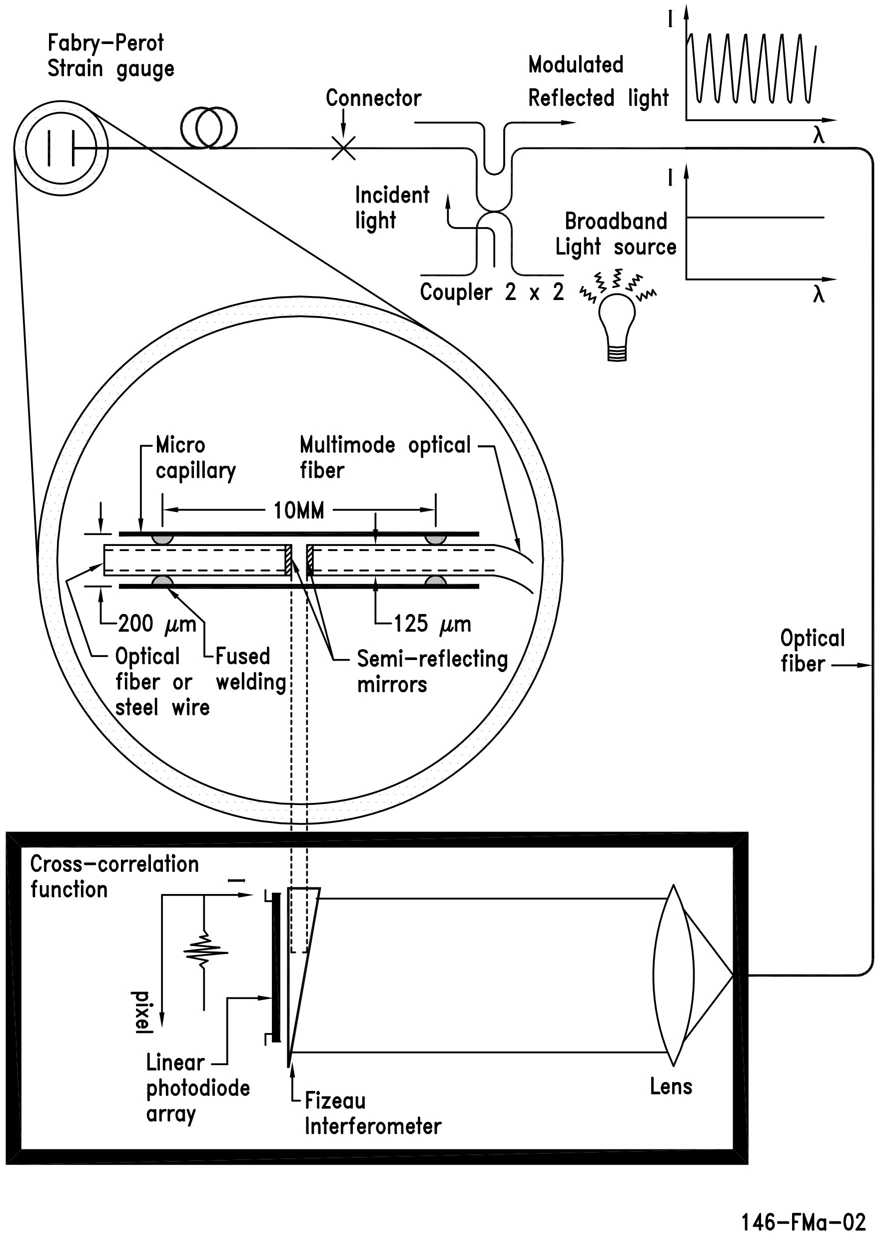


Figure 1: Schematic principle of a Fabry-Perot strain gauge

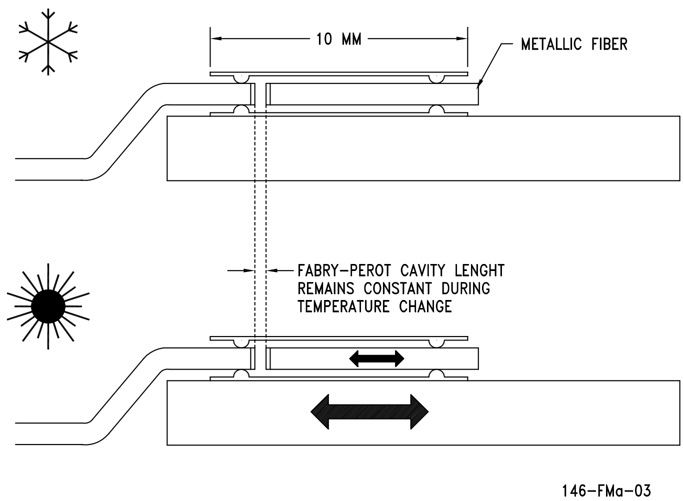
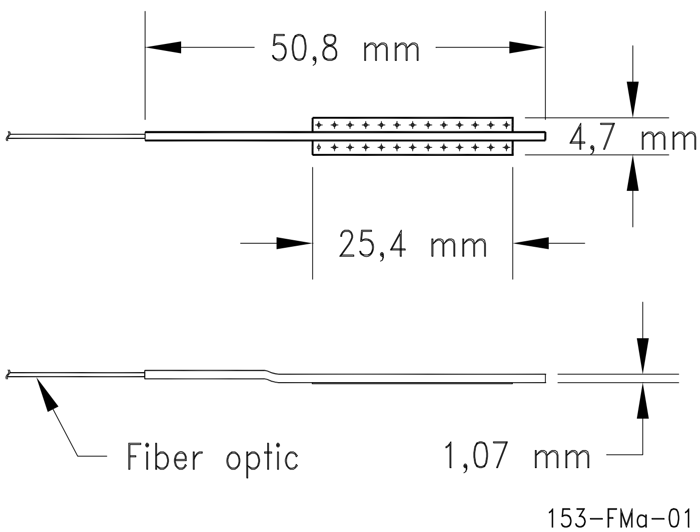


Figure 2: Principle of self-compensation mechanism

2.2 DESCRIPTION OF SFO-W STRAIN GAUGE

The SFO-W model is a spot weldable strain gauge. The gauge essentially consists of a stainless steel tube containing the fiber-optic strain gauge. A stainless steel foil, 0.15 mm thick, is welded to the tube. The foil is used to spot weld the gauge in place. The sensor is illustrated with relevant dimensions in Figure 3.



Top view

Side view

Figure 3: SFO-W Spot Weldable Strain Gauge

3 INSTALLATION PROCEDURE

3.1 IDENTIFICATION OF SFO-W GAUGE

Before installing and using the gauge, you must define it within the readout memory. To do this, you must enter its gauge factor (7 digit number, example: 1004103) in the permanent memory of the readout. After the gauge has been defined, you can connect the gauge to the readout. Please see the instruction manual of the readout you are using for more details.

The SFO-W has been designed to be installed onto steel structure using the portable strain gauge welding unit Model 700 or equivalent. Spot welding is a relatively simple operation requiring little skill, and the procedures to be followed are given in the instruction manual supplied with the spot welding unit.

The SFO-W gauge is designed for flat surfaces. However, it can be used on surfaces where the circular plane is normal to the gauge axis.

3.2 SURFACE PREPARATION

Safety goggles should always be worn during gauge installation to protect the eyes against metal particles both during surface preparation and actual welding.

For efficient welds, the surface to which the gauge is to be spot welded must be free of grease, rust, scale oxides and surface irregularities.

Steps for cleaning the surfaces are:

(1) Degrease the metal surface with an appropriate solvent such as Chlorothene or Acetone.

(2) Using a fine file or silicone carbide paper, remove rust and scale oxide to leave smooth bright surfaces where the sensor is to be welded.

(3) Thoroughly wash off dust using the solvent.

(4) Surface, if ground or filed, should be as flat as possible.

3.3 GAUGE SPOT WELDING PROCEDURES

Before actually attempting to install the SFO-W gauge for the first time, it is advisable to first practice using a small metal strip. Follow the instructions supplied with the welding set, make one spot weld and then pull the metal strip from the test surface; a small slug of metal should be pulled out of the test strip for a correct weld. On the Model 700 spot-welder, the weld energy should be set to approximately 25 for most applications.

Common welding problems include:

(a) Sputtering of the metal around the spot weld: this is due to excessive weld energy or electrode pressure.

(b) Weak weld; test strip pulls off without tearing out a slug: this is due to insufficient weld energy or electrode pressure.

(c) Sparking; this is usually due to insufficient electrode force, a dirty welding electrode or high contact resistance between the gauge foil and metal surface (poor surface preparation).

In all cases, it is essential to have a good electrical connection through the welding electrode to the welder "common" cable.

Gauge setting procedures are as follows:

(a) Align the SFO-W gauge on the metal surface: checking that the gauge foil sits flat on the surface. Read the gauge to make sure it is functioning properly. Next, tack it down in beginning on the side where is the fiber-optic cable and you must alternated on each side of tube.

(b) Continue to spot weld in following the sketch in figure 3 (page 3) to complete the installation. Roughly twenty-six (26) spot welds are recommended.

4 READING PROCEDURE

4.1 READINGS

The basic relationship between the reading and the change in strain in the investigated structure on which the gauge is welded is given by:

$$\varepsilon = \varepsilon_1 - \varepsilon_0$$

where: ε = Total strain change in structure, in μstrains

ε_0 = Initial strain, in μstrains

ε_1 = Current strain, in μstrains

Example for SFO-W strain gauge:

ε_0 = 3602.00 units, initial reading

ε_1 = 3039.80 units, current reading

$\varepsilon = \varepsilon_1 - \varepsilon_0$ = 3039.80 - 3602.00 = -562.20 μstrains (compression)

Positive values of ε represent tensile strains and negative values represent compressive strains.

4.2 TEMPERATURE SELF-COMPENSATED GAUGE AND NON-COMPENSATED GAUGE

One interesting feature of the SFO-W strain gauge is that it can be manufactured with either a temperature self-compensated or non-compensated Fabry-Perot strain gauge. When the temperature self-compensated gauge is used, the coefficient of expansion of the metallic fiber can be selected according to the thermal expansion of the structure on which the gauge is to be welded. So, correction factors for temperature effects caused by differential expansion can be negligible with this type of gauge. For an example see appendix A.

Roctest is proud to manufacture high quality instruments such as the SFO-W strain gauges. But Roctest denies any responsibility from the data interpretation. Appendix A is given only as a tool, providing two main approaches of data reduction.

5 SPECIFICATIONS

Gauge type:	SFO-W – spot weldable strain gauge
Readout units:	Universal white-light fiber optic signal conditioning from Fiso Technologies and Roctest Ltd
Ranges (micro-strains):	±1000, ±1500, ±2000 (other available on request)
Resolution:	0.01% full scale
Temperature range for proper operation:	-50°C to +85°C, cable dependent
Overall length:	76,2 mm
Overall width:	4,7 mm

Standard fiber optic

Cable: Polyurethane jacket, 4-mm diameter, multimode type

6 MISCELLANEOUS

6.1 TWO METHODS FOR INTERPRETING THE READINGS OF SFO-W

Following are two methods proposed depending on whether a temperature self-compensated or non-compensated Fabry-Perot strain gauge is used. These methods are proposed as tools for interpreting readings properly but in no matter Roctest should not be considered responsible if results obtained are not meeting expectations.

Total strain ε

Total strain ε is the raw strain obtained directly from SFO-W readings

$$\varepsilon = \varepsilon_1 - \varepsilon_0$$

where: ε = Total strain measurement, in µstrains

ε_0 = Initial strain, in µstrains

ε_1 = Current strain, in µstrains

This total strain contains the mechanical strains and thermal strains in the investigated structure. The two methods detailed below explain how to obtain the mechanical strain due to applied effective stress depending on whether a self-compensated or non-compensated Fabry-Perot strain gauge is used.

METHOD 1

Interpreting the readings with the non-compensated SFO-W strain gauge

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

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

Where: ε_r = Real strain, in µstrains

ε = Total strain reading, in µstrains

T_1 = Temperature reading of the structure, in °C

T_0 = Initial temperature reading of the structure, in °C

β = The expansion factor of the structure in μm/m/°C on which the gauge is welded, 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 for the first method:

ε_0 = 2200.2 units, initial reading SFO-W

ε_1 = 2407.8 units, current reading of SFO-W

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 we find the total strain, ε:

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

Therefore the real strain ε_r is:

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

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

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

METHOD 2

Interpreting the readings with self-compensated SFO-W strain gauge

With this second method, we use a self-compensated SFO-W strain gauge to find the effective strain applied.

This time, the thermal expansion of the metallic fiber in the self-compensated Fabry-Perot strain gauge (see section 2.1 for more details) is included in the formula.

$$\varepsilon_r = \varepsilon + (\alpha - \beta) \times (T_1 - T_0)$$

Where: ε_r = Real strain, in µstrains

ε = Total strain reading, in µstrains

α = Thermal expansion factor of self-compensated gauge (value provided by Roctest)

T_1 = Temperature reading of the structure, in °C

T_0 = Initial temperature reading of the structure, in °C

β = The expansion factor of the structure in µm/m/°C on which the gauge is welded, generally similar to 10 µm/m/°C < β < 16 µm/m/°C for steel. The β expansion factor is known from laboratory test.

Example for the second method:

ε_0 = 2200.2 units, initial reading of SFO-W

ε_1 = 2407.8 units, current reading of SFO-W

α = 11.0 µm/m/°C, thermal expansion factor of self-compensated gauge

T_0 = 20.2 °C, initial temperature reading of the structure

T_1 = 26.2 °C, current temperature reading of the structure

β = 12.0 µm/m/°C, structure expansion factor

Then the real strain ε_r is:

$$\varepsilon_r = \varepsilon + (\alpha - \beta) \times (T_1 - T_0)$$

$\varepsilon_r = (207.6) + (11 - 12) \cdot (26.2 - 20.2) = 213.6$ micro-strains

If therefore the thermal expansion factor of self-compensated gauge α is selected to be the same or similar of the structure expansion factor β (example: 12.0 µm/m/°C), then the total strain read is equal to the real strain. Then the formula is simplified and we obtain:

$$\varepsilon_r = \varepsilon$$

At this moment, the readings displayed on readout unit are the real strain, so:

$$\varepsilon = \varepsilon_1 - \varepsilon_0$$

ε_0 = Initial strain of SFO-W, in μstrains

ε_1 = Current strain of SFO-W, in μstrains