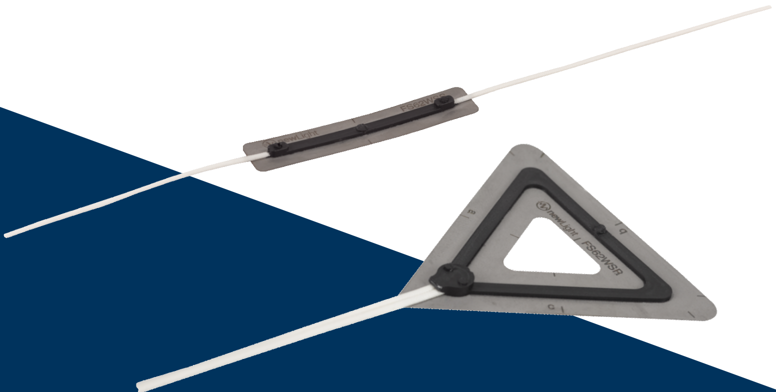
HBK FIBERSENSING

ENGLISH

Mounting Instructions



FS62WSS, FS62WSR (BRD)

Weldable Strain Sensor (Braided)
Weldable Strain Rosette (Braided)

HBM

Brüel & Kjær

Hottinger Brüel & Kjaer GmbH
Im Tiefen See 45
64293 Darmstadt
Germany
Tel. +49 6151 803-0
Fax +49 6151 803-9100
info@hbkworld.com
www.hbkworld.com

HBK FiberSensing, S.A.
Rua Vasconcelos Costa, 277
4470-640 Maia
Portugal
Tel. +351 229 613 010
Fax +351 229 613 020
info.fs@hbkworld.com
www.hbkworld.com

Mat.:
DVS: A05394 02 E00 00
07.2022

TABLE OF CONTENTS

1	**General Information**	**4**
2	**Sensor Installation**	**5**
2.1	List of materials	**5**
2.2	FS62WSS installation	**5**
2.2.1	Preparation of the installation area	**5**
2.2.2	Marking the measuring point	**8**
2.2.3	Positioning the sensor	**10**
2.2.4	Welding the sensor	**11**
2.3	FS62WSR installation	**16**
2.3.1	Preparation of the installation area	**16**
2.3.2	Marking the measuring point	**16**
2.3.3	Positioning the sensor	**16**
2.3.4	Welding the sensor	**18**
2.4	Routing and protecting the cables	**19**
2.5	Protecting the sensor	**21**
3	**Sensor Configuration**	**25**
3.1	Sensors documentation	**25**
3.2	Measurement computation	**25**
3.2.1	Temperature	**25**
3.2.2	Strain	**25**

1 GENERAL INFORMATION

The following instructions refer to the installation procedure of FS62WSS Weldable Strain Sensors and FS62WSR Weldable Strain Rosette with braided cable option.
These sensors can be delivered individually or in arrays of sensors preassembled in HBK FiberSensing facilities.

Material Numbers	
Strain Sensors	**Strain Rosette**
K-FS62WSS	K-FS62WSR
Sensor Arrays[1)]	
K-FS76BRD	

1) Only FS62WSS can be configured with FS62PSS and FS63LTS sensors using the K-FS76BRD material. For arrays of sensors including FS62WSR strain rosettes please contact HBK FiberSensing.

Information

This document is focusing on the installation of the FS62WSS and FS62WSR with braided cable. The installation of these sensors on its aramid and armor versions is similar, except for apparent difference in shape, size and cable handling. For detailed mounting instructions of the FS62WSS Weldable Strain Sensor or the FS62WSR Weldable Strain Rosette with aramid and armor cable please refer to the specific installation instructions.

2 SENSOR INSTALLATION

2.1 List of materials

Included material
Sensor(s)
Welding plate sample(s)

Needed equipment
Deburring Machine (optional)
Impulse Welding Device Recommended: similar to c33 from VBS Fuegetechnik

Needed material
Sandpaper.
Surface cleaning agents. Recommended HBK: 1-RMS1 or 1-RMS1-SPRAY
Tissues. Recommended HBK: 1-8402.0026
Drafting tape. Recommended HBK: 1-KLEBEBAND
Protection. Recommended HBK: 1-ABM75 and/or AK22

2.2 FS62WSS installation

2.2.1 Preparation of the installation area

The surface of the measurement object must first be cleaned and regular when installing the optical strain gauges or sensors. Remove all the paint and rust from the installation area until reaching a weldable material (*Fig. 2.1*). Ensure that there are neither irregularities nor debris left on the surface, as this would compromise the welding process. If needed regularize the surface in detail using a sanding paper.

Fig. 2.1 Surface deburring

Tip

Use the dummy sensor plate to define the area to prepare.

Fig. 2.2 Uneven and rusty surface unsuited for welding sensor

Fig. 2.3 *Surface sanding*

Fig. 2.4 *Ready to weld surface*

The surface needs then to be cleaned ensuring that no dust nor grease is present in the welding area.

Clean the surface using an appropriate cleaner degreaser (RMS 1 is suggested) and non-woven tissues (*Fig. 2.5* and *Fig. 2.6*).

Fig. 2.5 Using RMS1 cleaner and nonwoven tissues

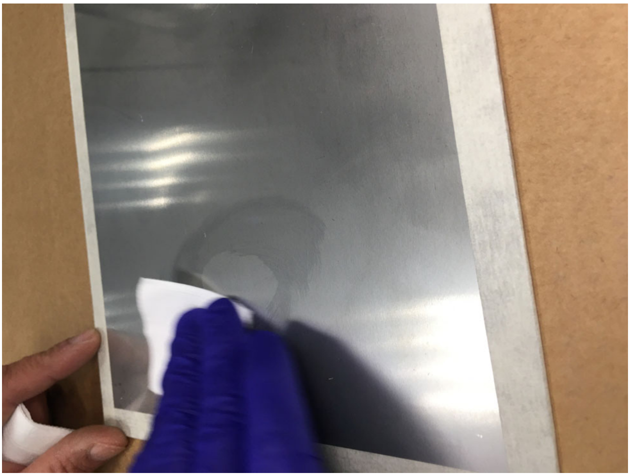


Fig. 2.6 Cleaning the surface

The wiping movements should always be performed in the same direction until the last tissue comes out clean.

2.2.2 Marking the measuring point

Define the alignment of the sensor considering the measurement direction and the sensor's central guidelines. This step is particularly important for the strain sensor as the sensor positioning dictates the measurement direction.

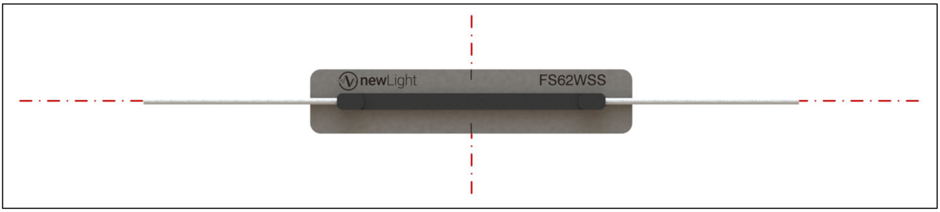


Fig. 2.7 Sensor alignment markings

Tip

Use a sharp tool or a pen, depending on the surface material, to mark the sensor position.

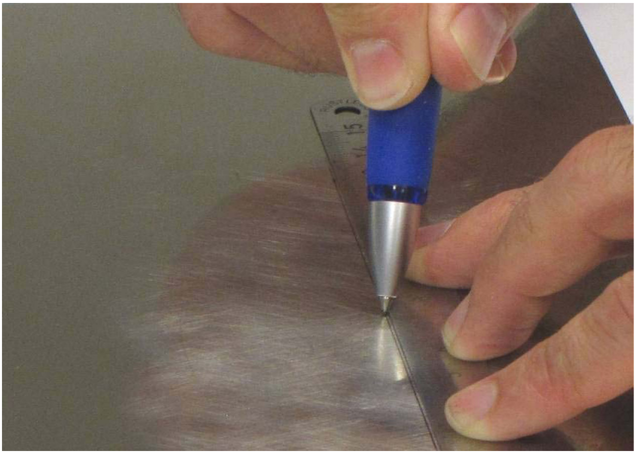


Fig. 2.8 Making the marking lines

2.2.3 Positioning the sensor

Prepare four pieces of tape: two with approximately 3 cm and two with approximately 7 cm (*Fig. 2.9*)

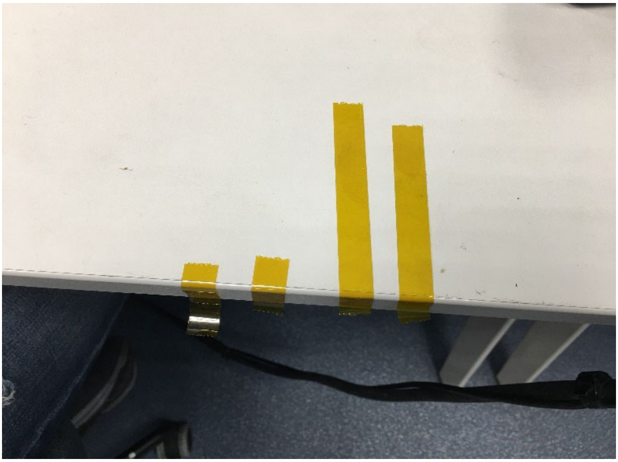


Fig. 2.9 Securing tape preparation

Carefully remove the sensor from the blister and align it with the drawn marks.
Using the smaller prepared tape pieces, secure the sensor cables in place (*Fig. 2.10*)

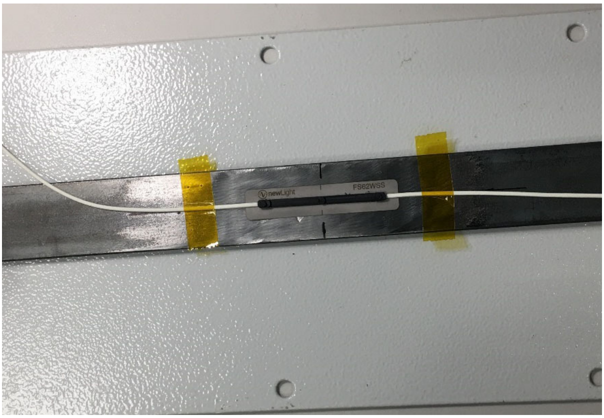


Fig. 2.10 First alignment

With the larger tape pieces fix the sensor's long borders to the specimen, covering about one millimeter of the sensor plate (*Fig. 2.11*). This will ensure that the sensor will not move during the welding process.

Notice

Ensure that welding area is free from tape. Performing the welding on areas with tape or glue will create an interference on the discharge that might ruin the sensor.

Fig. 2.11 Ensuring a smooth welding process by thoroughly fixing the sensor

2.2.4 Welding the sensor

HBK FiberSensing recommends the use of a similar model to c33 from VBS Fuegetechnik (www.vbs-fuegetechnik.de).

Fig. 2.12 Recommended Impulse Welding Device

Testing welding settings

Ideal welding settings may vary (depending not only on the used spot welder but also on material thickness, electrode position…). For that reason dummy welding plates for recipe tuning are delivered. Adjust the welding parameters by testing on the cleaned area away from the sensor position.

Tip

Spot weld the dummy plate and pull it to detach from the surface. For a good welding, this should be difficult to achieve and, once detached, the welding points should have become holes on the dummy plate as depicted in Fig. 2.13. Common settings should be with voltage between 40 V and 60 V.

Fig. 2.13   Correct welding settings confirmation

It is recommended that the electrode tip is trimmed flat and with approximately 1 mm diameter (*Fig. 2.14*).

Fig. 2.14 Electrode tip

Tip

Frequently trim the electrode during the welding procedure for the best results.

While welding, press down the welding pistol vertically (as shown in *Fig. 2.15*), one hand holding the pistol and the heel of the other hand pressing down the pistol from atop with force.

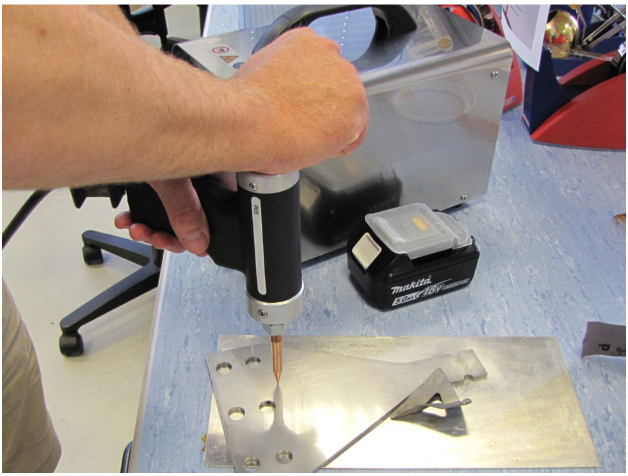


Fig. 2.15 Correct welding position

Welding procedure

The welding sequence should be performed from the middle to the outside of the sensors with points spaced at approximately 1 mm.

Follow the path as presented in *Fig. 2.16*.

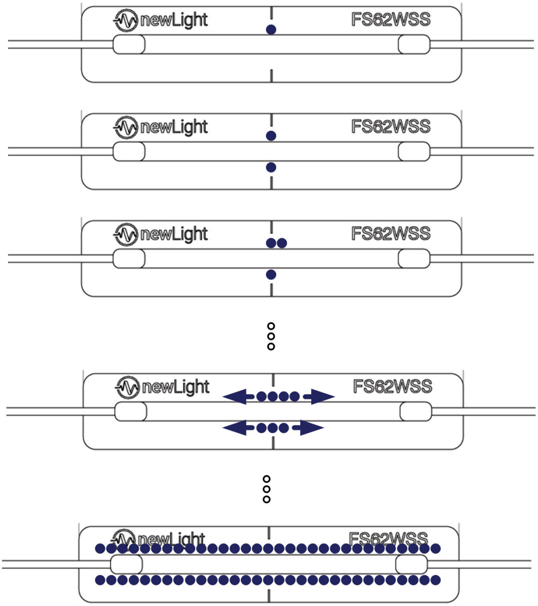


Fig. 2.16 FS62WSS BRD welding procedure

Fig. 2.17 Welding the sensor

Tip

When completely welded the FS62WSS on its braided cable version should have arround 35 welding points per line.

Fig. 2.18 Complete welding

2.3 FS62WSR installation

2.3.1 Preparation of the installation area

Proceed with the surface cleaning as described in *section 2.2.1 on page 5*, using the dummy plate as a reference to define the surface area that needs to be cleaned.

2.3.2 Marking the measuring point

The FS62WSR Rosette has three FBGs in a 0º/60º/120º position. The alignment of each FBG is evidenced by the sensor guides present at each corner of the rosette, which are defined as directions "a", "b" and "c", as shown in *Fig. 2.19*.

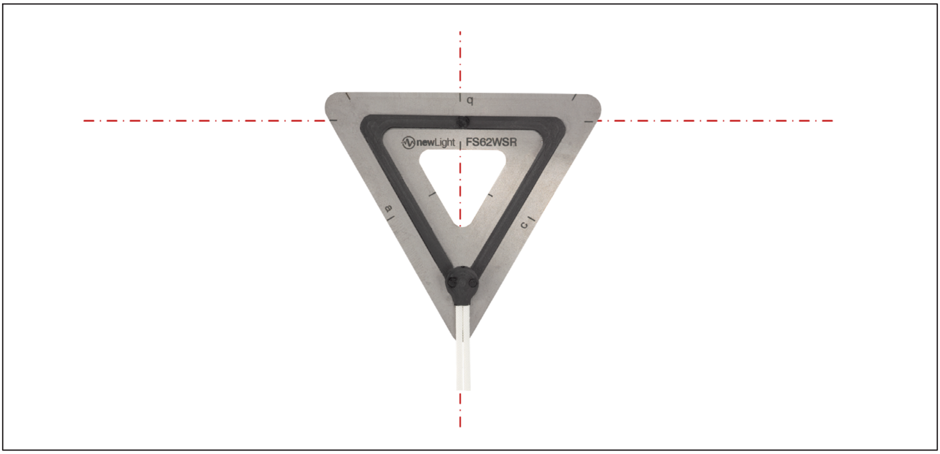


Fig. 2.19 FS62WSR Alignment marks

Start by drawing the marking cross, in a similar way to the described in *section 2.2.2 on page 8*, considering one of the FBG alignments, for example “b”, and its perpendicular.

2.3.3 Positioning the sensor

Prepare four pieces of an appropriate tape (example, masking tape). Three long enough to secure the three sides of the rosette triangle, and the fourth one to secure the cables

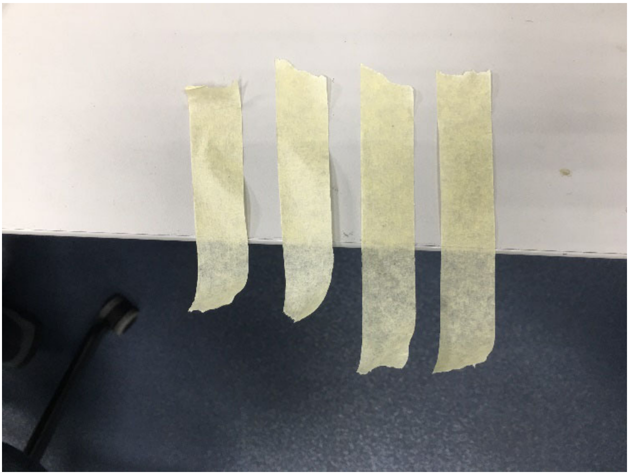


Fig. 2.20   Securing tape preparation

Position the optical rosette on the marking cross. Align the desired direction, for example “b”, with the horizontal marking. Refer to the alignment marks present on the sensor base to support on this positioning. Then align the perpendicular direction, for example between the lines pointing to the center of the “b” direction and the cable exiting between “a” and “c” directions.

Fig. 2.21   Aligning and securing the optical rosette

Secure the rosette in place using the tape by applying the tape along the sides covering about one millimeter.

Notice

Ensure that welding area is free from tape. Performing the welding on areas with tape or glue will create an interference on the discharge that might ruin the sensor.

2.3.4 Welding the sensor

Testing welding settings

Start by testing the welding settings following the procedure described in *section 2.2.4 "Welding the sensor", page 11*.

Welding procedure

The welding sequence should be performed from the middle to the outside of each of the FBG alignments with points spaced at approximately 1 mm.

Follow the path as presented in *Fig. 2.22*. Repeat for the remaining measuring directions.

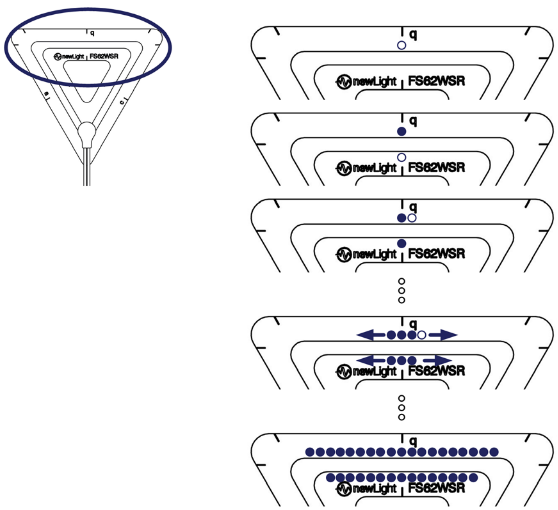


Fig. 2.22 FS62WSR BRD welding procedure along each measurement direction.

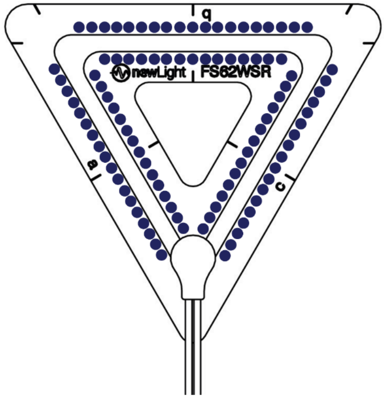


Fig. 2.23 FS62WSR BRD finished welding pattern.

Tip

When completely welded the FS62WSR on its braided cable version should have around 35 welding points, on the outside line, per orientation.

2.4 Routing and protecting the cables

Sensor cable should be routed ensuring that cables are not hanging and curvatures are kept within the limits for the used cable.

We recommend that strain relief is provided for the optical fiber *(see Fig. 2.24)*. Lay down the protruding fibers with gentle curves and fix them with polyimide adhesive tape. Alternatively, glue can also be used (for example X60).

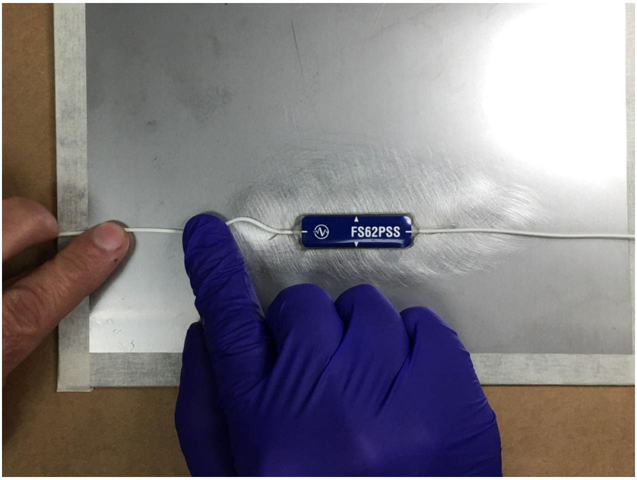


Fig. 2.24 Strain relief for the optical fibers

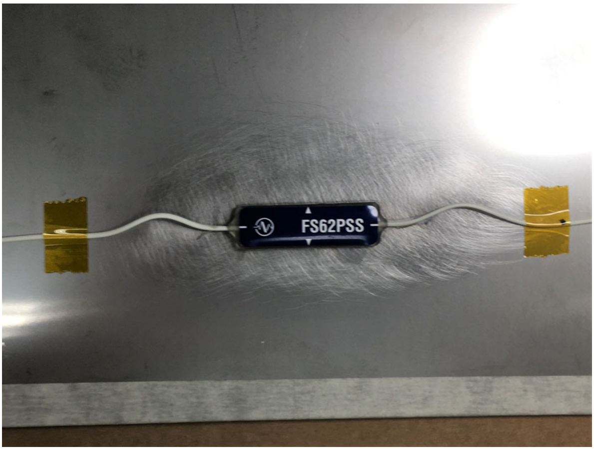


Fig. 2.25 Fixing fiber strain relief with tape

In case there are splice protections, ensure that the splice is also well fixed.

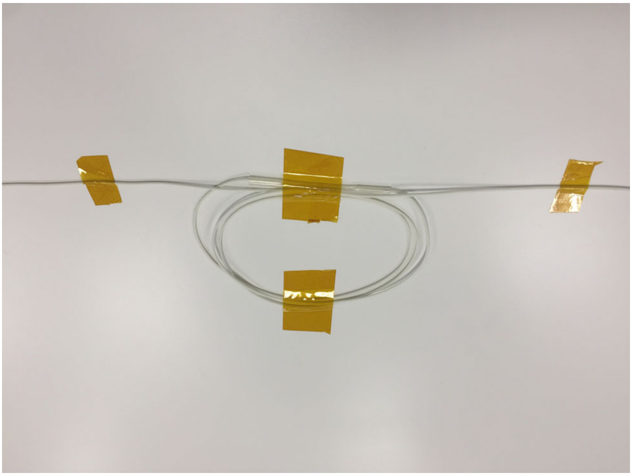


Fig. 2.26 Braided cable routing

For outdoor applications it is also advisable to further protect cable paths against moisture and mechanical damage. This can be achieved either by using cable conduits, or by covering the full length with silicone or other sealing paste (example DP490 from 3M).

Information

The braided cable is suited for laboratory installations in controlled environments. It can withstand an extended temperature range, but is not fully protected for mechanical damage. In case the sensors are used in harsh environments, further protection of the cables is recommended (using plastic tubes, conduits or covering the cables with protecting material).

2.5 Protecting the sensor

The FS62WSS and the FS62WSR are sensors designed for laboratory applications. Nevertheless they can be used in other environments if correctly protected.

Sensors should be protected against humidity effects with the covering agents AK22 and ABM75.

First cover all the adhesive residues (Z70 in this case), left over from gluing, generously with the covering putty. Carefully press the putty towards the sensor from all sides (*Fig. 2.27*)

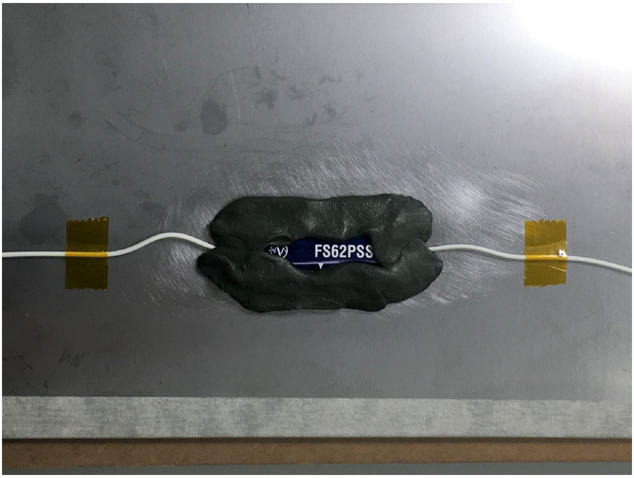


Fig. 2.27 Covering the sensors edges with AK22

Always include some AK22 below the cables to ensure complete coverage. This should be done next to the sensor, as well as on the interface of the remaining protective layers (*Fig. 2.28*).

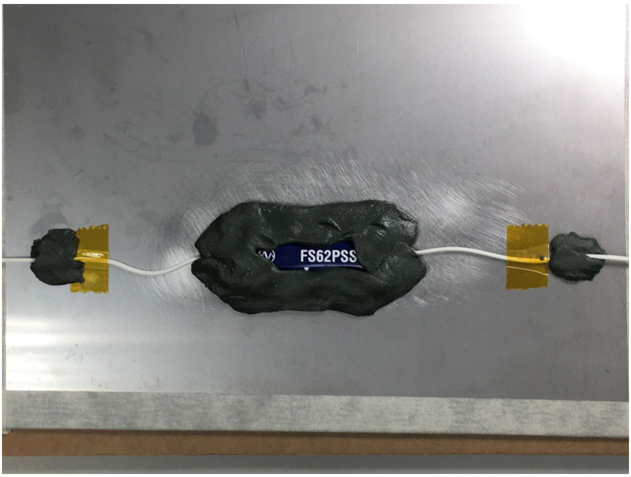


Fig. 2.28

Cut a piece of the covering foil ABM75 (*Fig. 2.29*), large enough to cover the sensor area (a single sensor or several close to each other – e.g. one FS62WSS and one FS62LTS for temperature compensation) and place it over the sensor.

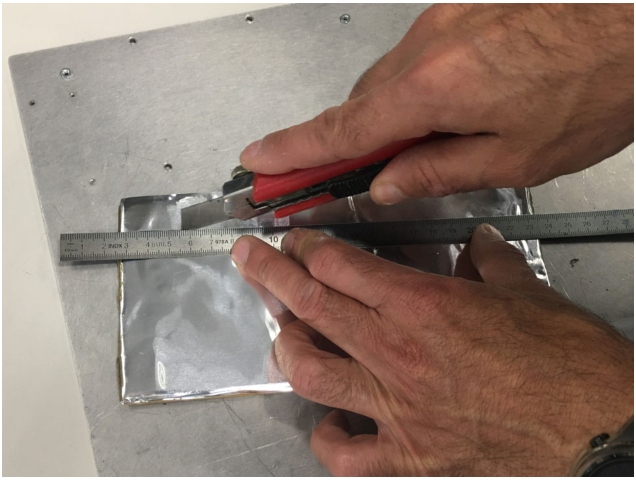


Fig. 2.29 Cutting ABM75 to fit the sensor area

Press the covering foil around its edges with a stiff element to tighten into the surface of the measurement object.

Notice

Pay extra care to not apply this pressure over the cable area as it can damage the fibers compromising the sensor reading. On the cable area this sealing should be ensured with your fingers.

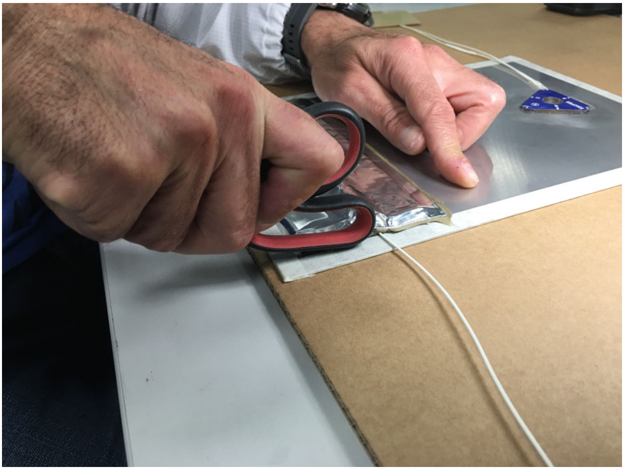


Fig. 2.30 Applying and pressing down the covering foil ABM75

Fig. 2.31 Completely covered measuring point

3 SENSOR CONFIGURATION

3.1 Sensors documentation

Calibrated HBK FiberSensing Sensors are delivered with a Calibration Sheet. Remaining sensors are delivered with a sensor Characteristic Sheet that contains important information for sensor configuration.

In the case sensors are delivered in arrays of pre-assembled sensors, a resume table with the relevant calibration information is provided in alternative.

Within the sensor's packing this installation instructions document is delivered in a printed version. Installation instructions can also be downloaded from HBK website (www.hbm.com).

3.2 Measurement computation

3.2.1 Temperature

The calculations that should be performed for converting a wavelength measurement into temperature are the shown in *Fig. 3.1*. The temperature value measured with a temperature sensor is given by a second order polynomial equation with coefficients obtained from the sensor calibration.

$$T = S_2(\lambda - \lambda_0)^2 + S_1(\lambda - \lambda_0) + S_0$$

Fig. 3.1 Temperature computation formula

Where

- T is the measured Temperature in ºC
- λ is the measured Bragg wavelength of the temperature sensor in nm
- λ_0 is the Bragg wavelength of the temperature sensor at reference temperature in nm
- S_0 is the zero order calibration factor (reference temperature) in ºC
- S_1 is the first order calibration factor in ºC/nm
- S_2 is the second order calibration factor in ºC/nm^2

When operating with catman® the values λ_0, S_0, S_1 and S_2 should be filled on the menu for temperature sensors configuration.

3.2.2 Strain

Strain sensors are not calibrated sensors. The characteristic sheet delivered with the sensor presents the sensor data for correct strain computation.

For the fiber Bragg grating strain sensors, wavelength variation including the effect of temperature is given by the equation shown in *Fig. 3.2*.

$$\frac{(\lambda - \lambda_0)}{\lambda_0} = k \cdot \left(\varepsilon_{Load} + (TCS + CTE) \cdot (T - T_0)\right) \cdot 10^{-6}$$

Fig. 3.2 Wavelength variation of a FBG strain sensor due to strain and temperature effects

Where

- λ is the measured Bragg wavelength of the strain sensor in nm
- λ_0 is the Bragg wavelength of the strain sensor at the reference instant in nm
- k is the strain k factor of the strain sensor, dimensionless
- ε_{Load} is the mechanical strain applied to the structure in µm/m
- *TCS* is the temperature cross sensitivity of the strain sensor in (µm/m)/ºC
- *CTE* is the coefficient of thermal expansion of the material of the specimen the strain sensor is attached to in (µm/m)/ºC
- $T\text{-}T_0$ is the difference between the actual temperature and the temperature at the reference instant in ºC

Measurement with no compensation

If no temperature compensation is required the strain computation can be done as shown in *Fig. 3.3*.

$$\varepsilon = \frac{(\lambda - \lambda_0)}{k \cdot \lambda_0} \cdot 10^6$$

Fig. 3.3 Simple strain computation formula (without temperature compensation)

Where

- ε is the measured strain in µm/m
- λ is the measured Bragg wavelength of the strain sensor in nm
- λ_0 is the Bragg wavelength of the strain sensor at the reference instant in nm
- k is the strain k factor of the strain sensor, dimensionless

Measurement with temperature compensation using a temperature sensor

Calculating compensated strain, in µm/m, using a temperature sensor is straightforward as the output of a temperature sensor is a temperature value in ºC. The calculation is depicted in *Fig. 3.4*.

$$\varepsilon_{Load} = \frac{(\lambda - \lambda_0)}{k \cdot \lambda_0} \cdot 10^6 - (TCS + CTE) \cdot (T - T_0)$$

Fig. 3.4 Strain computation with temperature compensation using a temperature sensor

Where

- ε_{Load} is the mechanical strain applied to the structure in µm/m
- λ is the measured Bragg wavelength of the strain sensor in nm
- λ_0 is the Bragg wavelength of the strain sensor at the reference instant in nm
- *k* is the strain k factor of the strain sensor, dimensionless
- *TCS* is the temperature cross sensitivity of the strain sensor in (µm/m)/°C
- *CTE* is the coefficient of thermal expansion of the material of the specimen the strain sensor is attached to in (µm/m)/°C
- *T* is the actual temperature measured by the temperature sensor used for compensation in °C
- T_0 is the temperature measured by the temperature sensor used for compensation at the reference instant in °C

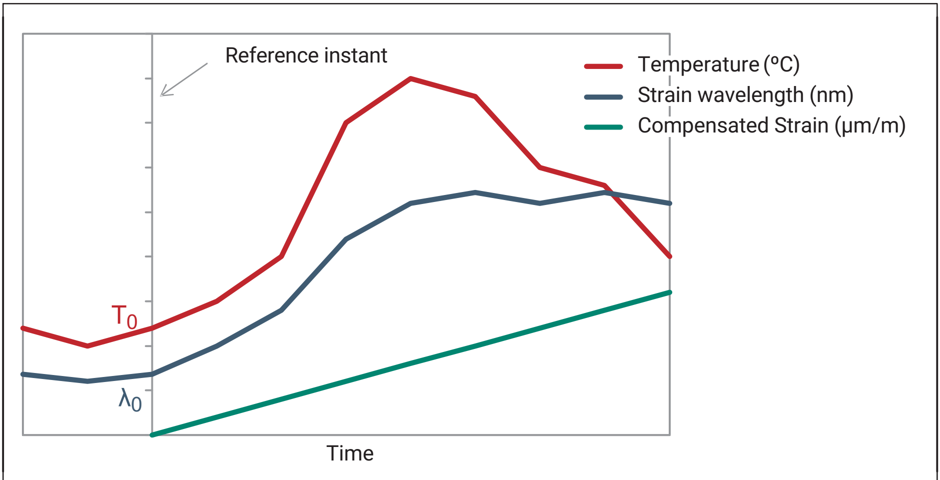


Fig. 3.5 Reference instant for temperature compensated strain measurement when using a temperature sensor for compensation

Measurement with temperature compensation using a compensation element

Strain measurement can also be correctly compensated using a compensation element based on FBG technology. Different approaches can be used:

- a temperature sensor without calibration certificate
- a strain sensor installed on a strain-free area of the same material
- a strain sensor installed on a strain-free material with a known CTE

The computation of strain can then be performed using the equation from *Fig. 3.6*.

$$\varepsilon_{Load} = \frac{\lambda - \lambda_0}{k \cdot \lambda_0} \cdot 10^6 - \frac{\lambda_{Tc} - \lambda_{0_{Tc}}}{\lambda_{0_{Tc}}} \cdot \frac{(TCS + CTE)}{TCF}$$

Fig. 3.6 Strain computation with temperature compensation using an FBG compensation element

Where

- ε_{Load} is the mechanical strain applied to the structure in µm/m
- λ is the measured Bragg wavelength of the strain sensor in nm
- λ_0 is the Bragg wavelength of the strain sensor at the reference instant in nm
- k is the strain k factor of the strain sensor, dimensionless
- λ_{TC} is the measured Bragg wavelength of the compensation element in nm
- $\lambda_{0\,TC}$ is the Bragg wavelength of the compensation element at the reference instant in nm
- *TCS* is the temperature cross sensitivity of the strain sensor in (µm/m)/°C
- *CTE* is the coefficient of thermal expansion of the material of the specimen the strain sensor is attached to in (µm/m)/°C
- *TCF* is the temperature compensation factor of the compensation element in (µm/m)/°C. For an uncalibrated temperature sensor this value is given on the sensor's characteristics sheet. For a strain sensor attached to a specific material TCF can be calculated as shown in *Fig. 3.7*.

$$TCF = (5.7 + k \cdot CTE_{TC})$$

Fig. 3.7 Temperature compensation factor computation

Where

- k is the strain k factor of the strain sensor attached to the temperature compensation element, dimensionless
- CTE_{TC} is the coefficient of thermal expansion of the material of the temperature compensation element in (µm/m)/°C

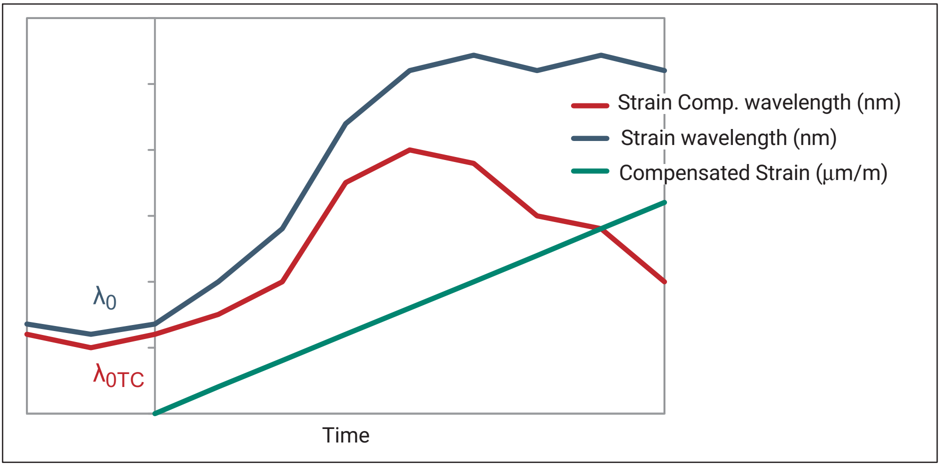


Fig. 3.8 *Reference instant for temperature compensated strain measurement when using an FBG compensation element*

Measurement with bending moment correction

When measuring on an element using a sensor that is far away from the attachment surface there may be an “error” on the measurement because the distance between the measuring point/alignment and the neutral axis is different to the distance between the installation surface and the neutral axis.

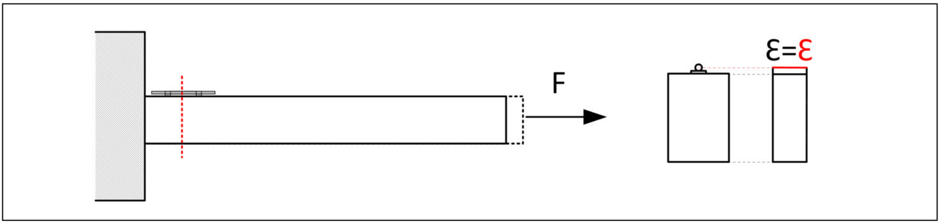


Fig. 3.9 *Strain on pure axial deformation*

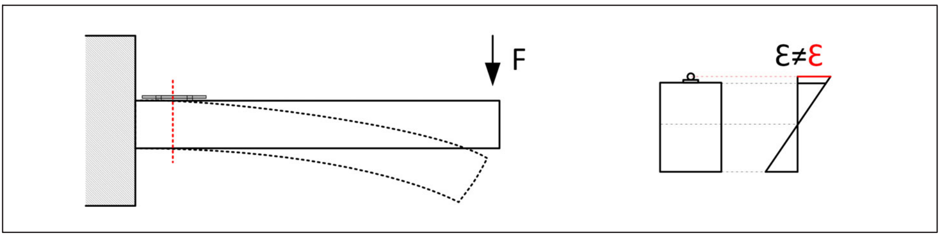


Fig. 3.10 *Strain on pure bending moment*

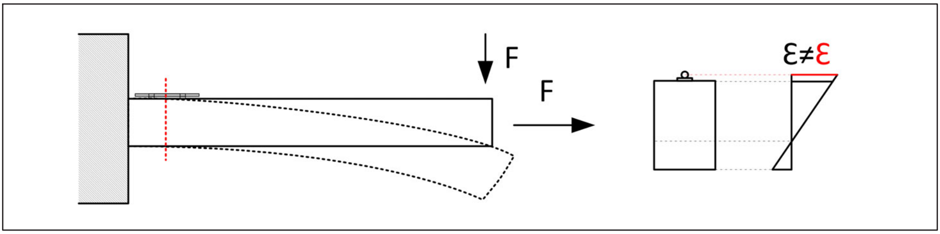


Fig. 3.11 Strain on axial load and bending moment

This becomes of high importance when the distance between the sensing element on the sensor to the attachment surface is relevant, or the measuring object is very thin. This distance on the FS62PSS Patch Strain Sensor and for the FS62PSR Patch Strain Rosette is 0.25 mm (h_2 on *Fig. 3.11*).

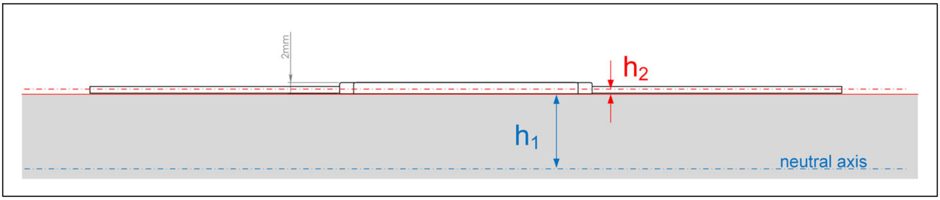


Fig. 3.12 Distance of the FBG to the mounting surface on the FS62PSS

However, knowing the distance to the neutral axis (h_1) the measured strain from the sensor can be corrected into strain on the surface by a geometrical factor:

$$\varepsilon_{surface} = \frac{\lambda - \lambda_0}{k \cdot \lambda} \cdot \frac{h_1}{h_2 + h_1} \cdot 10^6$$

Fig. 3.13 Strain computation bending effect correction

Where

- $\varepsilon_{surface}$ is the mechanical strain on the measuring surface in µm/m
- λ is the measured Bragg wavelength of the strain sensor in nm
- λ_0 is the Bragg wavelength of the strain sensor at the reference instant in nm
- k is the strain k factor of the strain sensor, dimensionless
- h_1 is the distance from the measuring surface to the neutral axis in mm
- h_2 is the distance from the measuring surface to the FBG in mm (0.225 mm for the FS62WSS and FS62WSR).

Measuring principal stresses

Principal stresses computation with the FS62WSR Weldable Strain Rosette can be calculated in accordance to the equation:

$$\sigma_{1/2} = \frac{E}{1-v^2} \cdot \frac{\varepsilon_a + \varepsilon_b + \varepsilon_c}{3} \pm \frac{E}{1+v} \sqrt{\left(\frac{2\varepsilon_a - \varepsilon_b - \varepsilon_c}{3}\right)^2 + \frac{1}{3} \cdot (\varepsilon_b - \varepsilon_c)^2}$$

Where:

- $\sigma_{1/2}$ are the principal stresses, in MPa
- E is the young modulus, in GPa
- v is the Poisson ration, dimensionless
- $\varepsilon_{a/b/c}$ are the the strains measured by the rosette on the three directions, in µm/m

The principal directions are the directions in which the principal normal stresses σ_1 and σ_2 occur as calculated using the equation above. Principal normal stress directions are defined by the angle φ that refers to the rosette's measuring directions, which can be determined using geometrical relationships from the strains ε_a, ε_b and ε_c measured with the rosette.

The aim of the following treatment is to provide the practical engineer with a convenient and reliable method. The theoretical aspects of Mohr's Stress Circle, which forms the basis of this treatment, are described in general literature.

First a tangent of an auxiliary angle ψ is calculated:

$$\tan\psi = \frac{\sqrt{3} \cdot (\varepsilon_b - \varepsilon_c)}{2\varepsilon_a - \varepsilon_b - \varepsilon_c}$$

Considering the signals of the numerator and denominator, the angle φ should be determined using the following scheme:

		Numerator $\sqrt{3} \cdot (\varepsilon_b - \varepsilon_c)$	
		Negative	Positive
Denominator $2\varepsilon_a - \varepsilon_b - \varepsilon_c$	Positive	$\varphi = \frac{1}{2} \cdot (180° - \lvert\psi\rvert)$	$\varphi = \frac{1}{2} \cdot (0° + \lvert\psi\rvert)$
	Negative	$\varphi = \frac{1}{2} \cdot (180° + \lvert\psi\rvert)$	$\varphi = \frac{1}{2} \cdot (360° - \lvert\psi\rvert)$

The angle φ found in this manner should be applied from the axis of the reference measuring position a in the mathematically positive direction (counter-clockwise). The axis of the measuring direction “a” forms one arm of the angle φ. The other arm represents the first principal direction. This is the direction of the principal normal stress σ_1 (identical with the principal strain direction ε_1). The point of the angle is located at the intersection of the axes perpendicular to the measuring directions. The second principal direction (direction of the principal normal stress σ_2) has the angle φ +90°.

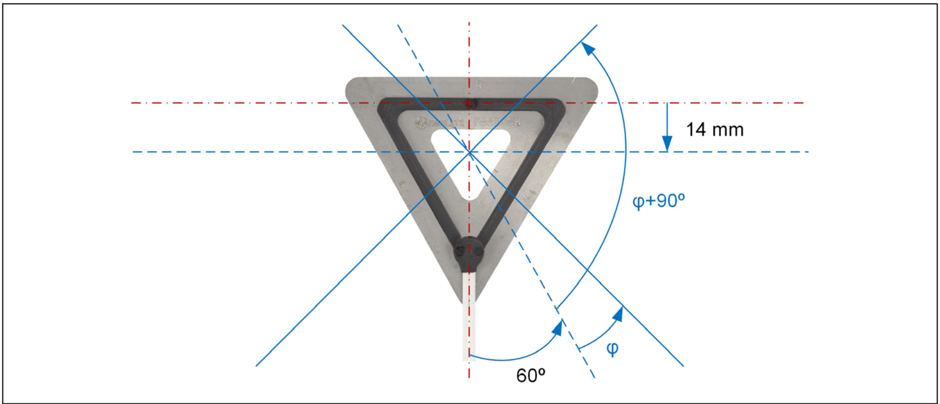


Fig. 3.14 Principal strain directions

HBK - Hottinger Brüel & Kjaer
www.hbkworld.com
info@hbkworld.com

A05394 02 E00 00