



Designation: E3410 – 24

Standard Practice for Strain Measurement Calibration and Verification of Fiber Optic Strain Gages¹

This standard is issued under the fixed designation E3410; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard provides uniform practices for the determination of Fiber Optic Strain Gage (FOSG) performance characteristics.

1.2 These practices apply to various types of FOSG interrogation technologies. Technologies used for interrogation include but are not limited to distributed interrogation techniques (for example, optical frequency domain reflectometry) and single-point techniques (for example, fiber Bragg gratings, extrinsic Fabry-Perot interferometers).

1.3 These practices specify procedures for determining the measurement uncertainty and verification of the spatial measurement resolution of both continuous FOSGs and discrete FOSGs. They are written to allow for the appropriate signal conditioner to be used with the FOSG technology being verified.

1.4 These practices only apply to the calibration and verification of FOSGs in static test conditions. These practices shall not be applied as written in dynamic or high-speed strain applications, nor shall the results of calibrations or verifications performed in accordance with these test practices be assumed valid for dynamic or high-speed strain measurements.

1.5 These practices include techniques for tension and compression testing of the FOSG. In cases where the system is capable of operating outside of the range that can be verified, the system only complies with this standard inside the range over which it was tested.

1.6 These practices do not define or rank the performance level of the FOSG but instead verify the performance level stated by the manufacturer.

1.7 Certain details regarding the execution of these practices are left to the user (for example, data sampling rate, dwell time, thermal settling time, specimen batch size). It is the responsibility of the user to determine and report these details such that the results could be replicated.

¹ These practices are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.01 on Calibration of Mechanical Testing Machines and Apparatus.

Current edition approved Sept. 15, 2024. Published October 2024. DOI: 10.1520/E3410-24

1.8 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards*:²

E6 Terminology Relating to Methods of Mechanical Testing
E83 Practice for Verification and Classification of Extensometer Systems

2.2 *Other Standards*:

JCGM 200:2012 International vocabulary of metrology—Basic and general concepts and associated terms (VIM)³

3. Terminology

3.1 *Definitions*:

3.1.1 Refer to Terminology E6 for the definitions of the terms batch, extensometer, extensometer system, gage factor, lot, metrological traceability, strain, and verification.

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *characteristic optical property, n*—a defining optical property (for example, wavelength) of the FOSG measured by the appropriate optical signal conditioner.

3.2.2 *continuous FOSG, n*—a FOSG that reports many individual measurements contiguously along a section of fiber where the location of measurement is user selectable.

3.2.3 *discrete FOSG, n*—a FOSG that has a discrete sensitive length at a fixed, non-user selectable location along an optical fiber and reports measurements at that discrete location.

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at www.astm.org/contact. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ International Vocabulary of Metrology—Basic and General Concepts and Associated Terms (VIM), 304th Ed., Developed by Joint Committee for Guides in Metrology, www.iso.org/standard/45324.html.

3.2.4 *Fiber Optic Strain Gage, FOSG, n*—A section of optical fiber that is used to give a measurement under an applied change in length.

3.3 Refer to the *International vocabulary of metrology—Basic and general concepts and associated terms (VIM)* for the definitions of calibration, calibration curve, coverage factor, expanded measurement uncertainty, indication, measurand, measurement error, measurement resolution, measurement uncertainty, and reference measurement standard.

4. Summary of Practice

4.1 *Basic Principles*—The application of strain to a FOSG will cause a corresponding output. This output is assumed to change in proportion to the amount of applied strain over the full measurement range of the FOSG; thus, a standard procedure is necessary for characterizing the response of the FOSG to an applied strain.

4.2 A range of strain input points are applied to the FOSG and held while the FOSG is measured using the appropriate optical signal conditioner. At each strain input point, measurements of the reference strain and the measured output are recorded. The comparison of the output to the applied strain is used for the computation of the calibration curve and measurement uncertainty.

4.3 The following procedures are applied to the FOSG by manufacturers to determine the performance of the FOSG and by end users to calibrate FOSGs and to verify manufacturer's specified spatial measurement resolution using the test apparatuses described in Section 7. This standardized set of test procedures allows for a baseline of statistical confidence in the results.

4.3.1 Section 7 presents four types of test apparatus: (1) fiber-stretching apparatus, (2) beam apparatus, and (3, 4) two types of spatial-measurement resolution measuring apparatus. Either the fiber-stretching apparatus or the beam apparatus shall be used to apply strain input points to the FOSG to create the calibration curve used to convert the measurement from the FOSG to engineering units. Either of the spatial-measurement-resolution measuring apparatuses shall be used to determine the spatial measurement resolution of FOSGs that claim such a specification.

4.4 A calibration system, consisting of a reference strain-measuring system, is specified. Calibration of the FOSG is accomplished through comparison of the measured FOSG behavior to the calibration system values.

4.5 Manufacturers shall ensure an appropriate number of FOSGs from a batch are evaluated with these practices to provide statistical confidence in the performance of any FOSG in the same batch. This confidence shall allow for any sample from the same batch to be measured following these practices and attain the same results with the stated tolerance from the batch. For determining measurement uncertainty, a minimum of ten FOSGs measured from the same batch shall be tested using an appropriate optical signal conditioner.

4.6 End users shall evaluate an appropriate number of FOSGs with these practices to provide statistical confidence in

the performance of any FOSG in the same batch. This confidence shall allow for any sample from the same batch to be measured following these practices and attain the same results with the stated tolerance from the batch. If ten FOSGs from the same batch are not available, each FOSG shall be verified using only non-destructive methods.

5. Significance and Use

5.1 FOSGs are used for measurement applications where the strain of a substrate or displacement between two datums is the measurand of interest. The performance parameters of the FOSG are affected by both the material and optical properties of the FOSG and the respective optical signal conditioner used to interrogate the FOSG. These practices detail the minimum information that shall be reported.

6. Interferences

6.1 General Interferences:

6.1.1 Ensure that all connections have been cleaned using appropriate manufacturer-specified techniques.

6.1.1.1 Repeat the cleaning at every instance of insertion of an optical fiber connector into a receptacle.

NOTE 1—Debris or oils, including finger oils, can interfere with the light path through the connection and could cause distortion to the signal.

NOTE 2—*Uncontrolled Environmental Interferences*—Uncontrolled and unreported temperature fluctuations that occur during a test will have significant impact on the efficacy of the device under test measurements.

7. Apparatus

7.1 *Optical Signal Conditioner*—The characteristic optical property output from the FOSG shall be measured by an optical signal conditioner that has metrological traceability to the SI per the manufacturer's recommendation or data sheet.

7.1.1 In the case of a FOSG designed with fiber Bragg gratings, the characteristic optical property of wavelength may be read by any suitable metrologically traceable optical signal conditioner.

7.1.2 Optical signal conditioners include those designed by the FOSG manufacturer to operate exclusively with proprietary FOSGs.

7.1.3 The measurement uncertainty of the optical signal conditioner shall be reported.

7.1.4 Operation of the appropriate optical signal conditioner shall be maintained within the manufacturer's specifications to comply with the stated measurement uncertainty.

7.2 *Fiber-Stretching Apparatus*—The fiber-stretching apparatus shall consist of a fiber stretcher that applies a known amount of linear displacement to a section of fiber and an enclosure to attenuate temperature and humidity fluctuations of the FOSG and that is equipped with a temperature-measuring system and a humidity-measuring system.

NOTE 3—The Fiber-Stretching Apparatus is only capable of calibration of the FOSG in tension. The Beam Apparatus is capable of both tension and compression calibration.

7.2.1 Fiber stretcher:

7.2.1.1 The fiber stretcher shall have the means to rigidly attach the optical fiber containing the FOSG to the stationary stage of the fiber stretcher.



7.2.1.2 The fiber stretcher shall have the means to attach a second point on the optical fiber to a movable stage such that the distance between the stationary stage and the movable stage contains the FOSG for which strain is to be evaluated.

7.2.1.3 The movable stage shall have a means of measuring its extension and retraction using a metrologically traceable micrometer to apply a known displacement (ΔL), and thereby an applied strain, based on a starting length (L), to the FOSG.

7.2.1.4 The fiber stretcher shall have a metrologically traceable length-measuring system capable of measuring the starting length between the stationary and movable stages. The accuracy of the length measuring system shall be at least 0.05 % of the starting length.

7.2.1.5 The measurement uncertainty of the metrologically traceable micrometer shall be at most one third of the target measurement uncertainty of the FOSG.

NOTE 4—For example, if the target measurement uncertainty of the FOSG is $\pm 1 \mu\text{m}/\text{m}$ on a 1 m sample of fiber the measurement uncertainty of the micrometer is less than $\pm 0.00033 \text{ mm}$.

7.2.1.6 The fiber stretcher shall be able to extend the FOSG to 110 % of the manufacturer's specified strain range.

7.2.2 *Enclosure*—The fiber stretcher shall be installed in an enclosure to attenuate temperature and humidity fluctuations of the FOSG and the fiber stretcher, as required by 10.2.4.

7.2.2.1 A system for controlling temperature and humidity may be employed so long as it meets the temperature and humidity requirements specified in 10.2.4.

7.2.3 *Temperature-measuring system*—The fiber-stretching apparatus shall have an independent temperature-measuring system capable of measuring the temperature of the FOSG with a metrologically traceable measurement uncertainty of no more than $\pm 0.25^\circ\text{C}$.

7.2.4 *Humidity-measuring system*—The fiber-stretching apparatus shall have an independent humidity-measuring system capable of measuring the humidity of the apparatus with a metrologically traceable measurement uncertainty of no more than $\pm 1\%$.

NOTE 5—A typical mechanical fiber stretcher is shown in Fig. 1. The fiber stretcher consists of a linear movable stage with a micrometer actuator at one end of a sufficiently stiff rail and a clamp and stationary (fixed) stage at the far end of the rail. The micrometer actuator incorporates a clamp for the optical fiber. The fiber stretcher is mounted in an enclosure with a transparent lid that is closed during operation to maintain temperature stability and shield the FOSG from air currents. The fiber containing the FOSG is inserted into the clamps, and the micrometer is used to apply strain to the fiber segment. The micrometer is stepped through a series of known displacements, with the characteristic optical property for the FOSG between the clamps recorded for each step with the appropriate optical signal conditioner.

7.3 *Beam Apparatus*—The beam apparatus shall consist of a constant-strain cantilever beam that exhibits a constant level of strain at a designated region where the FOSG, or multiple FOSGs, will be attached, a beam-deflecting mechanism for deflecting the constant-strain cantilever beam to produce known, repeatable strain input points, and an enclosure to attenuate temperature and humidity fluctuations of the FOSG and the beam apparatus, as required by 10.2.

7.3.1 *Constant-strain cantilever beam*:

7.3.1.1 The constant-strain cantilever beam shall have a metrologically traceable strain-measuring system capable of measuring the strain in the designated region. The strain-measurement system shall consist of two or more reference resistance strain gages, for use as reference measurement standards, that are permanently bonded to the constant-strain section of the constant-strain cantilever beam. An example of an acceptable beam is shown in Fig. 2.

7.3.1.2 The reference resistance strain gages shall be equally spaced no more than half the active gaging length apart along the length of the constant-strain cantilever beam. Install these reference gages using the best current techniques to ensure bonding integrity and long-term stability.

7.3.1.3 The reference resistance strain gages shall be individually calibrated to determine their gage factor by using a Practice E83 Class A extensometer system where the extensometer spans the reference strain gage, bending the constant-strain cantilever beam by means of the beam-deflecting mechanism, and measuring the resulting change in the gage resistance and strain.

7.3.1.4 The strain measurement uncertainty of the metrologically traceable strain-measuring system shall be at most $\frac{1}{3}$ of the target measurement uncertainty of the FOSG.

7.3.1.5 The constant-strain cantilever beam shall be designed to have a considerable area of uniform strain that is directly proportional to the deflection of the end point of the beam (the apex of the angle formed by the sides of the beam).

7.3.1.6 The size and arrangement of the beam apparatus shall be such that the constant-strain cantilever beam can be bent sufficiently in either direction to produce a surface strain of at least 110 % of the maximum strain specified for the FOSG under test in the manufacturer's specification sheet.

7.3.1.7 The constant-strain cantilever beam may be reoriented with its top surface facing down to achieve surface strain in both the positive and negative directions.

7.3.1.8 The frame of the beam apparatus shall be much more rigid than the constant-strain cantilever beam to prevent errors due to bending of the frame.

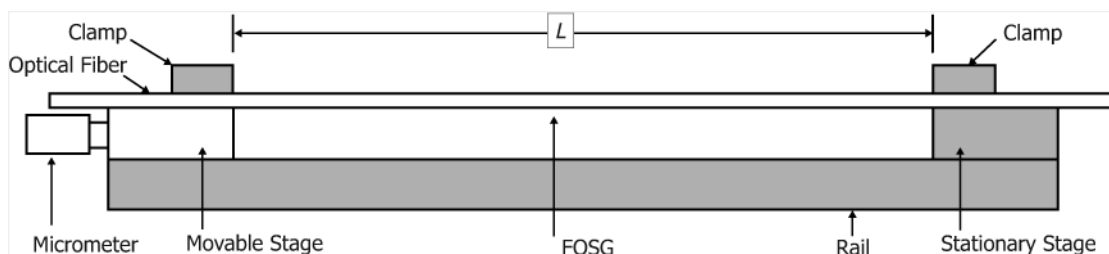


FIG. 1 Diagram of a Fiber Stretcher