GUIDLINES FOR USE OF FIBRE OPTIC SENSORS

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on behalf of SG3/WG4

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FOS GUIDELINE

1. Introduction
2. General terms
3. Functionality
4. Response characteristics
5. Quantities of random nature
6. Optical safety quantities
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2. General terms

This category describes terms affecting all or most Fibre Optic Sensors

- **Type of used fibre**
- **Type of sensor**
- **Distance range**
- **Measurement range**
- **Wavelength of operation**
  - **characteristic wavelength @ reference temperature (FBGs)**
- **Gauge factor / scale factor @ reference conditions**
- **True value**

Type of used fibre

It is a known category of fibre used for FOS construction. If FOS is affected using a specific type of fibre, this must be indicated.

Type of the sensor

It is physical base of sensor operation as: a distributed sensor (which is sensitive over the whole fibre length), point sensor (which is represented by a discrete (single) sensitive element or a chain/number of sensitive elements).

Distance range

It is the fibre length over which the measurement can be performed within the stated uncertainty and spatial resolution.

Note: For attenuation-limited systems it can be calculated as follows: Distance range [km]= (Optical budget [dB] - connection loss [dB])/Linear attenuation of fibre [dB/km])

Measurement range

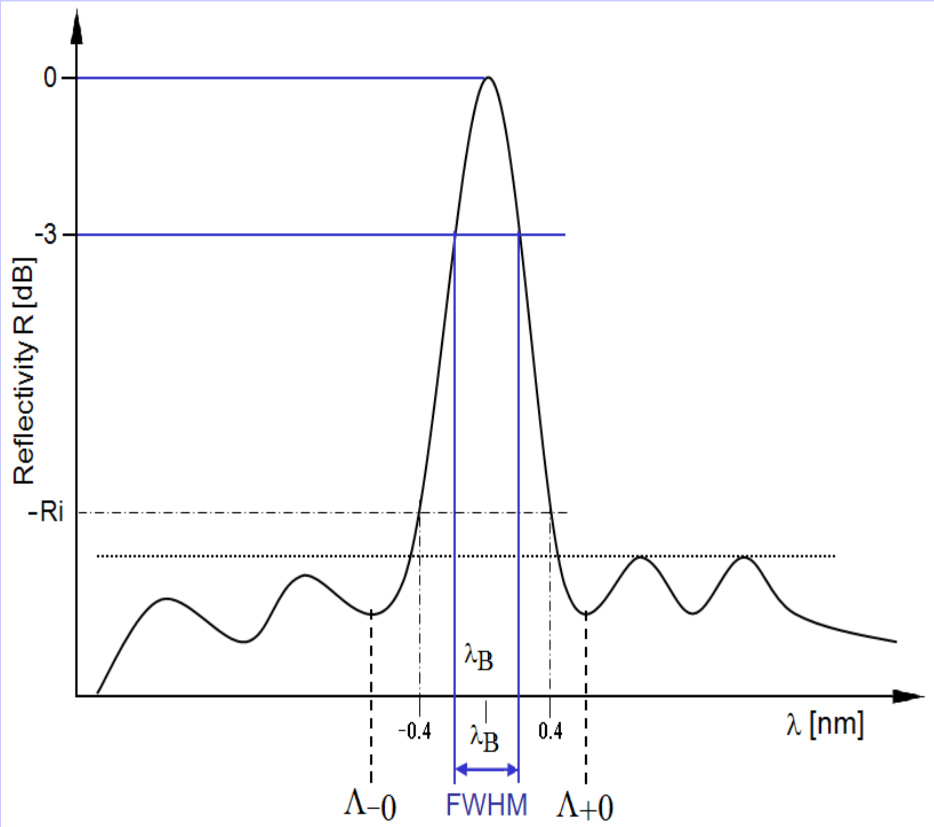
It is defined by the minimum and maximum allowable values of the measurand.

Note: It may be limited by several factors, e.g. onset of unacceptable non-linearities, mechanical issues, etc.

Wavelength of operation

It is the wavelength (range of wavelengths) of optical radiation which the sensor users in order to provide the required information.

Characteristic wavelength @ reference temperature (FBGs): It is the wavelength that characterizes the sensor response at reference temperature monitored by the interrogator. It shall be given together with the experimental and numerical method used for its determination.



Note: The characteristic wavelength can be measured as the maximum value of the peak in reflection or as minimum value of the transmission spectra.

Important characteristics of FBG for sensors:

- Peak wavelength [nm];
- Peak wavelength deviation at room temperature [nm];
- Peak reflectivity [%];
- FWHM peak width (-3-dB band-width) [nm];
- Side lobe sup-pression at ± 0,4 nm [> xx dB];
- Λ+0, Λ-0 (first poles (minima) of the Bragg grating reflection peak);
- Pulse stability (Side lobe suppression);
- Reflectivity above the amount Ri with a typical spectral width of more than +/- 0.4 nm around the Bragg wavelength. For this width no additional peaks (side lobes) are expected.

Gauge factor / scale factor @ reference conditions

It is specification how the input quantity of a measurement device is changed into the output quantity.

Note: Sometimes the term strain factor or K factor is used whereas then a linear characteristic has to be assumed. The gauge factor can separately be defined for the components of a measurement system. It is only valid for defined conditions. In case of non-linear characteristic, the gauge factor can be linearized within defined amount of permissible error. Reference condition include values and ranges for the influence quantities affecting the measurement system.

True value

It is the result of a measurement that would be obtained by a perfect measurement.

Note: Because true values are by nature indeterminate, there may be many values consistent with the definition of a given particular quantity. A number of results of measurements enables to establish best estimate for the true value with the minimum uncertainty. This estimate is called conventional true value, assigned value, sometimes reference value. The conventional true value can have an uncertainty appropriate for a given purpose which is generally accepted by convention. The expression "reference value" in this sense should not be confused with the term reference value refered to reference conditions that are prescribed for performance tests or for intercomparison of results of measurements.

3. Functionality

This category describes terms useful during FOS works

- **Fatigue**
- **Life expectancy / lifetime**
- **Durability**
- **Failure criteria**
- **Gauge length**
- **Sampling interval**
- **Optical power dynamic range**
- **Warm-up time**
- **Measuring time**
- **Updating time**
- **Limiting conditions**

Fatigue (zmęczenie)

It is a change of the result due to accumulation of mechanical damage.

Note: It can be influence by the method of sensor attachment to the measured object and materials used.

Life expectancy / lifetime (prognoza żywotności)

It is a period of time during which the measuring system or its components are operating according to all its specifications in given conditions.

Note: In this time the system will perform its internal function, satisfactorily or without failure, e.g. within specified performance limits, when used in the manner and for the purpose intended, while operating under the specified application and operation environments with their associated stress levels..

Durability (trwałość)

It is related to the quality of a manufactured component of a measurement system or of the whole measurement system and indicates how well it withstands a sustained period of specified operation. It comprises the degree to which the system or its components can withstand physical, chemical, or environmental factors.

Note: A durable item can be used over a definite, mostly long period without being degraded or consumed.

Failure criteria (warunek uszkodzenia)

It is the measurement uncertainty (overstress, overheating, etc.) which exceeds the specified level or no results are provided.

Note: A component is considered faulty if it no longer meets applicable mandatory requirements listed in the data sheet.

Gauge length (odległość wskazań)

It is the length of the measured object over which the sensor gathers information. For example, if the sensor is only anchored at two fixed points L cm apart, then the GL is L. On the other hand, if a sensor of length *l* is continuously-fixed in or to a measured object of length L, then the actual GL depends on the method of attachment to the measured object and is a function of the mechanical properties of both the sensor and its surrounding; it is generally longer than *l* but shorter than L.

Note: If a user wants to achieve a pre-determined GL, he must be very careful in selecting the procedure by which the sensor is anchored/attached/embedded. In case of continuously-fixed sensors, the fixing length must exceed the defined GL by a few tens of fibre diameter to avoid shear-lag problems at the edges. In the specific case of fracture or cracks within the GL of the sample, the final gauge length must be calculated then from the GL at fracture by subtracting from the latter the elastic portion of the elongation.

Sampling interval

It is time interval between two consecutive data points digitized by the sensing device, normally converted to distance given in metres, using user-defined parameters such as refractive index.

Note: It may depend on the distance range and other sensing device settings. The sampling interval is consequently a non-physical parameter and does not contain any information about the spatial resolution of the measurement system itself. It however contributes to the distance and location uncertainties.

Optical power dynamic range

It corresponds to the maximum cumulated one-way or two-ways loss (it must be indicated) in the optical link between the interrogator and the measurement point that makes possible a measurement with a specified performance.

Note: The measurement uncertainty, resolution and interrogator settings (pulse width, averaging time etc.) are interdependent and cannot be specified independently. In particular, loss budget can be improved at the expense of increased averaging time and/or uncertaintanty of measurement.

Warm-up time

It is the duration from power-on until the system performs in accordance with all specifications

Measuring time

It is the required duration to obtain the result of a measurement (IOS VIM93 3.1) within specified uncertainty, spatial resolution and distance range.

Updating time

It is the duration between two subsequent results produced by the measuring system.

Limiting conditions

They are extreme conditions that a measuring instrument is required to withstand without damage or without degradation of specified metrological characteristics when it is subsequently operated under its rated operating conditions (acc. to VIM 93 5.6)

4. Response characteristics

This category gives correlation between output quantities of a measurment system and corresponding quantitative characteristics of the measurand

- **Resolution**
- **Spatial resolution:**
  - **- Measuring spatial resolution**
  - **- Detection spatial resolution**
- **Full Scale**
- **Scale factor**
- **Responsivity**
- **Measurement dynamic range**
- **Linearity**
- **Cross-senstivity**
- **Drift**

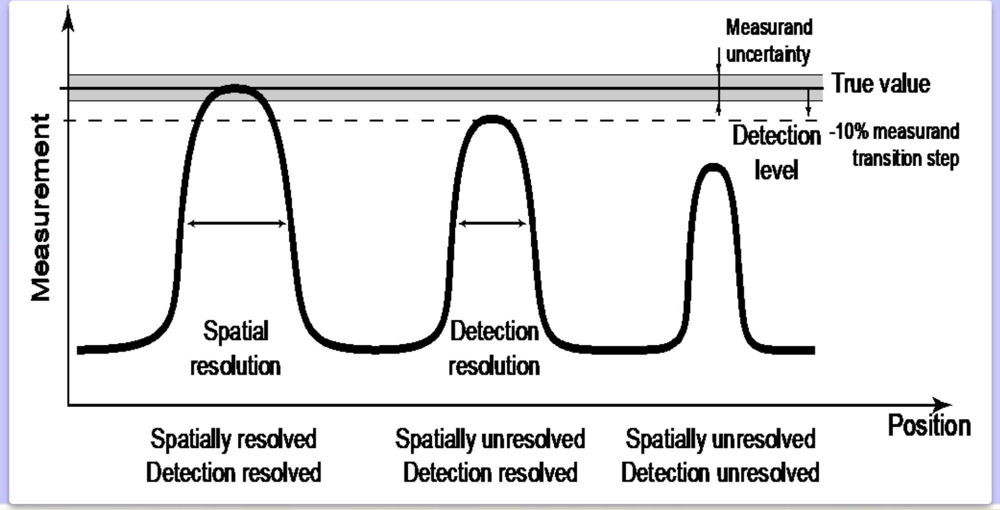
Resolution (rozdzielczość)

It represents the smallest change in the measurand, meaningfully detectable by the measurement system. The resolution is limited by either the instrument readout or precision (σ), whichever is bigger.

Spatial resolution is specified for a fiber by the minimum distance between two step transitions of the measurand of at least 20 times its resolution.

Measuring spatial resolution is the minimum distance over which the system is able to indicate the value of the measurand within the specified uncertainty.

Detection spatial resolution is the minimum distance that generate results that are within 10% of the measurand transition amplitude.



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Full Scale

It is the largest allowable value of the measurand.

Note: Full scale may be limited by several factors, e.g. onset of unacceptable non-linearities, mechanical issues, etc.

Scale factor

It is the inverse of the ratio of a change in the stimulus to corresponding measured change. It may depend on the value of the stimulus.

Responsivity (czułość)

It expresses the change in the response (output signal) of a complete measurement system to the corresponding change in the stimulus (input signal).

Note: It may depend on the value of the stimulus, then the responsivity must be specified separately for each value. Normally, it is not dimensionless and cannot be expressed in percent.

Measurement dynamic range

It is the ratio of the difference between the extremes of the measurement range (measurement span) to the resolution (the smallest detectable change), often expressed in dB.

Linearity

It is the tolerance to which a response characteristics of a measurement system approximates a straight line in the measurement dynamic range.

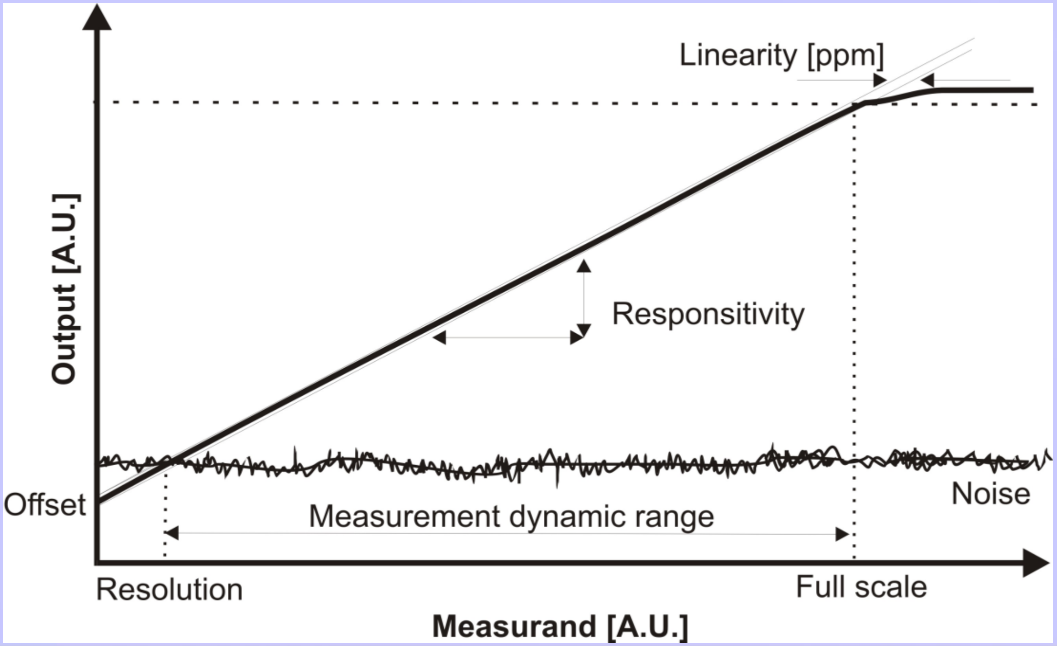
Note: Practically, deviation from linearity is usually expressed in ppm.

Drift

It is It is a slow change of the metrological characteristics of the measurement system.
Note: It indicates a lack of stability due to environmental and operational affects, material effects (e. g. creep of adhesive) or storage conditions. Drift effect in a running measurement system causes a change of the output signal without variation of the input signal. Drift must be evaluated and indicates how often a measurement system needs recalibration. It must be distinguished between recalibration of devices and applied sensors (which is usually complicated or impossible). Concerning the scale factor, it can suffer from drift from zero or offset drift, or from a drift from the slope, or combinations of both. The estimated amount of the drift has to be expressed as an error estimate in the measurement result.

Cross-sensitivity

It is unwanted change of measurement result due to influence of physical factors other than the measurand.
Note: Typically, this is influence of temperature on mechanical sensors



5. Quantities of random nature

These quantities describe unpredictable variations in measurement results affecting system reliability

- **Accuracy:**
  - **- Location accuracy**
  - **- Distance accuracy**
- **Precision**
- **Repeatability**
- **Reproducibility**
- **Uncertainty of measurement**
- **Bias**
- **Noise**
- **Stability**

Accuracy (dokładność)

It qualitatively expresses the closeness of the measured value to the true or ideal ('master') value of the measurand. It represents the difference between the measured result and the true value and is affected by both bias and precision.

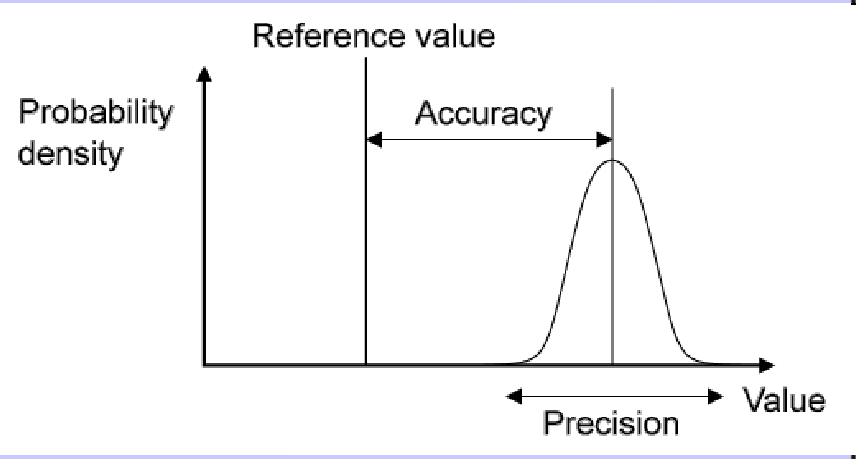
Note: Accuracy should not be confused with the term precision. Achieving high accuracy requires careful control of all factors influencing operation of measuring system, e. g. temperature, barometric pressure, etc.

Location accuracy The displayed location minus the true location. This error is a function of the location.

Distance accuracy The distance between two events provided by the measurement device minus the true distance.

Precision (precyzja)

It describes how repeatable a measurement result is. It is expressed by the estimated standard deviation of a specified series of measurements. (Sometimes precision is expressed as a multiple of the estimated standard deviation, e.g. 2σ). The smaller the dispersion of the measured values, the better the precision; precise measurement results need not to be necessarily accurate (e.g. due to bias). Therefore a result of a single measurement should be interpreted as drawn from an ensemble with the measured standard deviation.



Repeatability (powtarzalność)

It is closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement (acc. to VIM 94, 3.6)

Reproducibility (odtwarzalność)

It is closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement (acc. to VIM 94, 3.7)

Uncertainty of measurement (niepewność pomiarowa)

It means doubt about the validity of the estimate y for the measurand Y and reflects the lack of knowledge of the exact value Y. Uncertainty is expressed by a parameter uc(y), associated with the result of measurement y that characterizes the dispersion of the values that can reasonably be attributed to the measurand. The parameter can be an estimated standard deviation (or a given multiple of it), or the half-width of an interval having a stated level of confidence.

Note: The evaluated dispersion uc(y) must be additionally reported to the estimate y of the measurand Y; it should preferably be stated in the ways proposed in the 'Guide to the Expression of Uncertainty in Measurement' (GUM), ISO 1995, chapter 7. The dispersion comprises uncertainties evaluated from the statistical distribution of the results of series of measurements, and also unknowable quantities due to possible errors. Uncertainty of relative measurements is usually significantly lower than the uncertainty defined above and rather depends on precision and drift.

Bias

It is the difference between the measured result after averaging and the 'true' value. The true value can be obtained either by measuring a reference standard maintained by the national standard organizations or by using a traceable measuring instrument.

Noise

It is a random variation in the measurement result unrelated to the measurand. It primarily affects the precision of measurement.

Stability

It is the ability of a measurement system to maintain its metrological characteristics and meet other specifications over the intended service time.

6. Optical safety quantities

The cited guidelines refer to safe use of fibre optic sensors with laser-based interrogators

Laser class

Safety of laser products. Part 1: Equipment classification and requirements (IEC 60825-1:2007) and Part 2: Safety of optical fibre communication systems (OFCS)

Note: power of the laser source is classified according to the accessible emission limit (AEL) which is - from the medical point of view - related to the Maximum permissible exposure (MPE)

Laser safety

EN 207, e. g. DIN EN 207:2008 - CE Marking and Laser Protective Eyewear

EN 208, e. g. BS EN 208:1999 - Personal eye-protection

Note: EN 207 is the European norm for laser safety eyewear and cosidered as a guide to understanding the standard for laser user

EN 208 applies to Visible lasers only (i. e. 400 - 700 nm wavelength range). Standards for laser use are nationalized.

7. Sources

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