

## Advances in Developing Standards for Fibre-Optic Sensors

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### ABSTRACT

Fibre optic sensors provide a great potential in different industrial as well as research fields. They are always then increasingly used if special requirements avoid the application of conventional electrical sensors. The scientific background for optical fibre sensors is well developed; however, not all users are already convinced that fibre optic sensors enable long-term stable function under harsh environmental conditions. There are still some restrictions with respect to long-term reliable use: first, some sensor products available on the market are sometimes not appropriately characterized and described. Second, application procedures are not always well validated due to a lack of understanding the mechanical, physical or chemical issues in the interface zone between sensor and measuring object.

Industrial users therefore need standardized description of the sensor system performance, recommendations what aspects have to be considered for reliable application and operation of sensors, and finally how to handle the application of sensors under possibly harsh environmental conditions. Technical rules must be provided. First guidelines for the appropriate specification and use of fibre optic sensors have been developed and published. Several European and international activities have been launched to push the development of further standards for special applications.

The paper informs about successful standardization activities. Worldwide running relevant guideline activities are presented. An outlook on important research activities to come to substantiated statements in standards is given.

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## INTRODUCTION

The quality of a measurement system is represented by the reliable use of system components. Mostly, the weakest point is the sensor itself, and its use under real measurement conditions. Therefore, several essential technical details have to be considered when selecting sensor type, application method and materials, e. .g:

- Thermal stress loading on sensing element during application
- Sensor reaction to mechanical or thermal impacts (shocks) during operation
- Sensor behaviour/aging under maintained vibration
- Sensor behaviour (including cabling) under wet conditions
- Creep of applied sensor depending on temperature
- Drift of the sensor signal depending on temperature and other influences
- Durability of materials under thermal, chemical, mechanical conditions.

When users are going to solve a measurement task, they need a comprehensive overview on basic characteristics of the sensor system components, their performance as well as basic rules how to use the measurement system practically. This use generally includes the selection of appropriate system components, the selection of appropriate and long-term reliable installation components such as fixing elements, adhesives, covering materials. Finally, established application procedures must be used to eliminate weaknesses and avoid failure of installed sensor components.

When using rather new sensor technologies such as the fibre sensor technology, some more aspects have to be considered. One aspect concerns the terminology used in this field. Physicists do speak another language than practitioners or system designers. Another often seen lack concerns the performance description of the system components. The non-availability of standardized testing methods to prove the performance of fibre-optic sensors often causes problems. For example, there was a long way to come to standards for resistance strain gauges and corresponding devices. Today, a number of standards, guidelines and certified application procedures (including training programmes to get a certificate) are established that enable users to get reliable measurement results from applied resistive strain sensors.

In the same way, the established use of fibre-optic sensor systems on-site requires standards and guidelines. No aerospace company will integrate fibre-optic measurement systems in their airplanes without having got any standards that describe and define important parameters and procedures. At least, hand-outs or company-related guidelines (which are not yet standards) generally summarizing the wanted information for design, application and operation of fibre-optic sensor systems must be available. Users need precise information about the component's characteristics, reproducibility, long-term stability, expected drifts and creep, parameter limits, and eventually, information about the expected uncertainty of the results measured. The design work for a sensor system and the choice of an appropriate application procedure must follow specific demands according to the measurement task.

In the past few years, several activities have therefore been started to come to standards and guidelines for fibre-optic sensors. This paper summarizes those activities and includes few important aspects that should be reflected in related standards and guidelines. A more detailed description of different expectations of fibre-optic standards and guidelines can be found in [1] and [2].

## **GUIDELINES AND STANDARDS—CURRENT SITUATION**

Development of standards and guidelines for fibre-optic sensor's performance specification, and relevant testing procedures have been discussed in the scientific community as well as in industry since the mid-nineties of the last century. There are a very large number of standards for description, evaluation and use of fibre-optic components in data communication and telecommunication. Guidelines or substantial standards for fibre-optic sensors were still an exception. The first standard draft on generic specification of fibre-optic sensors - IEC 61757 - has been published in 1995; the first Working Draft P952/D24 for a specific type of a fibre sensor - the fibre-optic gyroscope - has been published in December 1996. The IEC standard 61757, part 1: 'Generic standard' has been revised in 2010 and 2011, and was in the FDIS status (Final Draft International Standard, which contains the text intended for publication for final approval) in early 2012 [3]. Publication of this standard was in April 2012. The gyro standard draft is meanwhile basis for the gyro production [4].

The most important prerequisite when a new measurement technology is to be launched is the availability of a consistent ("standardized") terminology. Not only different users make use of non-consistent terms and descriptions for the fibre-optic sensor technology, but not even all of the fibre sensor experts carry the same understanding what specific terms associated with characterization, validation and application of sensing systems do mean. It is worthwhile to notice that standards for fiber-optic sensors have also to cover characteristic details related to the respective physical sensor mechanism, to the sensor response to different measurands, to application, and finally to specific perturbing influences coming from environmental situation. These sensor-specific issues mark other aspects in fibre-optic sensor technology, and is in the scope of standardization step-by-step.

Subsequently, a short overview about most relevant activities in standardization of fiber-optic sensors including activities to promote the standardization work is given.

### **European activities within COST actions**

Besides the first activities to establish the generic Fibre Optic Sensors standard (IEC 61757) and the Gyro-Standard, there were some more activities to establish an international research project in Europe. The objective is to extend the standardization activities to specific sensor types and to develop and launch guidelines for the most requested fibre optic sensors to measure strain profiles, temperature distribution and vibrations on/in large structures to assess their structural integrity. In July 2004, a very effective European group formed from 13 institutions proposed the collective EU research project "Development of Guidelines and Standards for Reliable Commercial Use of Fibre Bragg Grating Sensors" (DOGSTAR) which addressed the issue of the lack of recognized standards for fiber Bragg gratings (FBGs) and FBG measurement systems. Although the first stage of submission and evaluation was successful, a number of small and medium companies originally highly motivated were not able to join this research project because of unfavourable prerequisites for subsidies. Eventually, this early activity to push specific standardization activities in Europe was not successful.

A new start at the European level has finally been made within the COST-299 action “FIDES” (Optical Fibres for New Challenges Facing the Information Society) in 2005 for a period of four years (until January 2010). This scientific platform consolidated a respectable number of fibre sensor experts from all over Europe, from very different topics and application fields. This platform provided an excellent basis for the discussion of terms and very important details for appropriate use of fibre optic sensors. Working Group 4 of this action: “New Challenges in Fibre Optic Sensors” dealt with the development of guidelines for preferably long gauge length sensors. In order to support an appropriate design and use of fibre-optic sensor systems, undoubtedly clear definitions of sensor-specific terms and clear information on sensor characteristics were developed by an international expert group. It was not possible to cover all different aspects of fibre-optic sensors in the COST 299 “Guideline for the use of fibre-optic sensors” [5]; however, it includes the following sub-items:

- 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.
- Functionality; this category describes terms useful while working with fibre optic sensors: fatigue, life expectancy/lifetime, durability, failure criteria, gauge length, sampling interval, optical power dynamic range (optical budget), warm-up time, measuring time, updating time, limiting conditions.
- Response characteristics; this category describes terms which give correlation between output quantities of a measurement system and the corresponding quantitative characteristics of the measurand: resolution, spatial resolution, measurement dynamic range, scale factor, responsivity, linearity, drift, cross-sensitivity, full scale.
- Quantities of random nature; this category describes terms specifying unpredictable variations in measurement results affecting system reliability: accuracy, location accuracy, distance accuracy, precision, repeatability, reproducibility, uncertainty of measurement, bias, noise, stability.
- Optical safety related quantities; the cited guidelines refer to safe use of fibre optic sensors with laser-based interrogators.
- Sources, references.

These European COST activities were reorganized and extended within the new ICT COST TD 1001 action “Novel and Reliable Optical Fibre Sensor Systems for Future Security and Safety Applications (OFSeSa) started in November 2010 [6]. The objective was to facilitate and promote end-user adoption of state-of-the-art fibre-optic sensor systems for reliable use in safety and security relevant applications in society, through the establishment of standardized characterization and application procedures, which required a highly interdisciplinary and strongly coordinated European-wide approach. In the working group WG 3 “Sensor Characterization & Onsite Evaluation”, the key requirement of companies which are interested to provide high-quality products manufactured, tested, specified and validated according to international guidelines are discussed. There are four study groups in the WG 3: Sensor interfaces, test procedures, on-site implementation & validation, and standardization. Some of related special aspects are validation of fibre-optic sensors for long-term use and validation of interrogation systems for reliable data recording under adverse conditions. This international COST platform run until November 2014

and is open for all experts from industry, research and consulting who are interested to collaborate.

### **German standardization activities**

In Germany, three small and medium companies (AOS Dresden, FBGS Jena and HBM Darmstadt) dealing with fibre-optic strain sensors based on fibre Bragg gratings insisted that guidelines for manufacturing and use of Bragg grating based strain measurements are developed. This was the starting signal for the joint project to develop the VDI/VDE 2660 Guideline: “Optical strain sensor based on fibre Bragg grating - Fundamentals, characteristics and sensor testing” [7]. This guideline is the first fibre-optic sensor standard that focuses on specific fibre optic strain sensors based on fibre Bragg gratings. It was developed under the roof of the German expert committee 2.17 “Fibre optic sensors” within the VDI - “The Association of German Engineers” as a cooperative work together with two research institutes (IPHT Jena, BAM Berlin). This guideline was published in July 2010 in a bilingual version (English/German).

This activity was driven by the permanent discussion of reliability-related aspects in the measurement technology’s community when fibre-optic strain sensors are used on sites. The VDI/VDE 2660 guideline provides directive technical and scientific procedural documentation and decision-making aids for manufacturers, distributors and users of FBG strain sensors. It treats significant technical questions from scientific and economic standpoints and formulates assessment and evaluation criteria that facilitate the technology transfer of new products. The guideline covers the most important terms and aspects for manufacturers and users, all quality assurance aspects arising during manufacturing, testing, storing, and finally the use of fibre Bragg grating strain sensors in different fields. Important issues addressed in the guideline are:

- Terms and definitions
- Design-specific features and characteristics to be measured
- Recurring specifications for characteristics testing
- Test devices requirements for use in test facilities and on site
- Statement of the measurement results for investigated characteristics.

Because optical strain sensors (OSS) based on FBG sensors are usually designed in different ways, the OSS are divided into three different engineering designs: a) as a fibre with one or several sensors along its length (FBG array), b) as extensometer sensor whereas the fibre ends of the grating are fixed at two points with definite distance, and c) as a FBG patch, where the grating is embedded in a protective layer or directly fixed to a carrying frame. Basic terms are defined, such as gauge length, strain, reference strain, wavelength reference, stability criteria for the optical strain sensor, zero-point related and non-zero-point related measurement; moreover, Bragg wavelength, spectral width, reflectivity, strain sensitivity (k-factor characteristics), ultimate strain for room temperature, fatigue behaviour, minimum bending radius, response to temperature changes, and temperature-correlated strain. Another aspect concerns parameters of the FBG that define the Bragg wavelength with respect to the calculation algorithm used in the interrogating device. Another important section of the VDI/VDE 2660 guideline focuses on the requirements for certified testing

facilities used by manufactures to characterize FBG-based sensors. Recommendations are also given on how to state the measured results. Therefore, the guideline refers to the GUM [8], as well as to the corresponding standard which ensures the use of calibrated and validated testing facilities [9]. Finally, the guideline presents a model of a data sheet, which lists a number of functional characteristics that have to be specified, such as Bragg wavelength, k-factor characteristics, response to temperature changes, spectral width, and reflectivity. The model data sheet also recommends a number of other important specific parameters and design specifications that provide comprehensive information for designers and users of such sensor systems. Manufacturers and users who observe the recommendations of this guideline are allowed to sell their products with the cachet: “Qualified according to guideline VDI/VDE 2660”.

This initially German guideline is being proposed to integrate it into the IEC fibre-optic sensor standards family. It should be developed as IEC standard 61757, part 2 in the WG 2 of the sub-committee SC 86C (interested co-workers are invited; please contact the author).

In 2010, more R&D activities have been started in Germany within a research program partially supported by the German Federal Ministry of Economics and Technology. This program "Transfer of R&D results by standardization" enables German research organizations to work together with experienced companies with the objective to integrate results of industrial research into standards. The challenge is to transfer such high-technology results into products that can be launched into the global market. On the other hand, these activities prepare and initiate new standards on the national (e.g. DIN), European (CEN/CENELEC) and international (ISO/IEC) scale. One of these projects deals with the development of composite-embeddable fibre Bragg grating strain sensors, and of validation methods and test apparatus for characterization of applied and embedded fibre-optic strain sensors. Another project deals with the development of standards for the use of fibre-optic sensors in the offshore environment. Special emphasis is given to the optimization and validation of a reliable sensor function as well as the development of appropriate methods of application and installation under extremely harsh environmental conditions.

## **INTERNATIONAL STANDARDIZATION ACTIVITIES**

### **Subsea Fibre Optic Monitoring (SEAFOM) guidelines**

Development of guidelines for the use of distributed temperature sensor systems is driven by SEAFOM Working Groups. They represent an international joint industry project promoting the growth of fibre optical sensing in subsea applications. The members of the SEFOM group come mainly from oil and gas industry and focuses on international standardization of subsea optical monitoring and sensing functional and test parameters. The use of distributed temperature sensors in high-power grids is also in the focus.

The first SEAFOM-MSP-01 guideline “Measurement Specification for Distributed Temperature Sensing“ (DTS) has been published in March 2010 [10]. The SEAFOM-MSP-01 document is used as a guide to enable the characterization of performance of any DTS as defined by the measurement parameters. It describes a



harmonized set of DTS performance testing procedures. Measurement performance parameters such as calibration error, spatial resolution, repeatability of temperature measurements, spatial temperature resolution, environmental temperature stability and warm-up time are specified. Additionally, parameters that support the definition of the measurement specification and their associated test procedures are defined: temperature sample point, temperature trace, distance range, total fiber length, sampling interval, start-up time, temperature disturbance width, and some more. This guideline is accompanied by another one: SEAFOM-TQP-01 “Functional Design and Test Requirements for an Optical Feedthrough System used in Subsea Xmas Tree (XT) Installations”, published in February 2011 [11]. This document specifically addresses the interface between the subsea environment of the XT and the downhole or reservoir environment for transmission of optical data through the XT. From the IEC perspective, the idea is to integrate these fibre-optic sensor documents into the IEC 61757 fibre-optic sensors family in the near future.

### **Society of Automotive Engineers (SAE)**

Another international (industry-driven) standardization activity is done in the Society of Automotive Engineers (SAE), in the Technical Committee AS-3: “Fiber Optics and Applied Photonics” [12]. The fibre-optic sensors sub-task group is composed of developers, manufacturers, and users of fibre-optic sensors for preferably aerospace applications. The purpose is threefold: First, the development of a set of standards that will define the function, installation, operating parameters ranges and interface requirements for fibre optic sensor applications; second, elaboration of standards that apply to fibre optic sensors used in aerospace; third, generating interface standards. The interface standards will cover electronic and optical interface methods, and standard requirements for interface devices such as interrogators. Currently, well-prepared drafts of guidelines are under revision, e. g. Aerospace Resource Document ARD 040711 “Fiber Optic Coupled Sensors for Aerospace Applications” and Aerospace Information Report AIR6031 “Fiber Optic Cleaning” which contains information relating to available cleaning materials, their pros and cons, and recommended practices. There is a good communication between the key players of the SAS committee and those in the other standardization committees.

### **Progress in standardization**

In view of the numerous requests to get standards and guidelines for the most often used fibre-optic sensors, the IEC activities in standardization of fibre-optic sensors are being expanded. In spring 2012, a New Work Item Proposal (NP) was communicated to the members of the SC 86C, and interested experts from all countries are invited to join the activities to be started in autumn 2012. It is planned to develop and/or to integrate further guidelines into the IEC standards and regulations family. The next parts of the IEC 61757 fibre-optic sensor standard family should contain a) strain sensors based on fibre Bragg gratings, b) distributed temperature sensors, c) distributed strain sensors, and finally d) local temperature sensors. First relevant documents for these activities are the existing VDI/VDE guideline [7] and the SEAFOM document [10].

## STANDARDS REQUIRE EXPERIMENTAL TECHNIQUES

Sensor standards have to provide substantiated statements on the performance of virgin (delivered by the manufacturer) and finally applied sensors. Very often, there is still a serious discrepancy between results achieved in laboratory environment and on site. To define binding statements and recommendations in standards and guidelines, some experimental investigations are needed to prove the behaviour of sensors and sensor systems. In most cases, special facilities are needed to get physically independent results, i. e. the test results must be generated by using a reference method but not only from any comparative measurement. Very important details of such investigations concern e. g. the long-term static or the dynamic behaviour of materials under thermal and mechanical cycling, the type of adhesive and other materials to be used for application of sensors, statements on the strain transfer factor and its stability (strain transfer behaviour of strain sensors). First results in development of reference methods and facilities to support calibration, validation and certification of sensor systems were made with the putting into operation of the KALFOS facility [13] at the BAM Federal Institute for Materials Research and Testing in Berlin. More details about the validation, partially surprising validation results with established strain sensors, and important aspects to get reliable measurement results can also be found in [14], [15]. The next step is the development of validation methods and adaptation of corresponding facilities for material-embedded fibre-optic sensors.

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