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OPTICAL FIBER USED AS SEA WATER THERMOMETER

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Abstract–In the framework of the EMRP project “ENV 58. Metrology for essential climate variables”, a new technique to perform traceable temperature measurements of the sea water profile and sea water surface will be studied, developed and applied to a real situation. This new thermometer consists on several Bragg gratings located at different points along an optical fiber, getting a thermometer based on distributed temperature sensors, that will be used to measure the sea water temperature profile. This technique will provide additional and valuable information about the evolution of the sea environment behaviour.

Keywords: marine environment, distributed temperature measurements optical fiber, traceability, calibration, uncertainty, Bragg grating.

1. STATE OF THE ART

The sea characteristics evolution with time are an indicator of climate and atmospheric changes. This has motivated an increase of the number of studies about the sea in recent years. Nowadays, an important number of such studies are focused on the measurements of parameters like acidity, salinity or acoustic noise, being the sea water temperature one of the most important parameters related with climate change. This fact highlights the importance to perform reliable and traceable monitoring of such parameter, in order to have an indication of the climate realistic evolution. Currently, the sea temperature is mainly measured by three different methods: in the first one, the temperature measurement is performed via satellite observation; in the second method, thermometers are attached to buoys that can be launched into the sea or can be located in a fixed position; the third one consists on research campaigns by ship, where different arrays, known as CTD [1], are launched in order to perform measurements of Conductivity, Temperature, and Depth. Each technique presents its own disadvantages, like, it is not possible to measure sea temperature at higher depth than 1 meter by satellite, the buoys provide measurements at a fixed position and the research campaigns by ship are expensive and do not supply continuous monitoring of the sea parameters for long periods of time.

This paper describes the activities included in the EMRP ENV58 project that will be carried out involved in the use of distributed thermometer sensors based on an optical fibre will be described and analyzed as a way to perform traceable and reliable measurements of the evolution in time of the sea profile temperature and sea surface temperature .

After the analysis of the performance of the optical fiber as thermometer and the evaluation of all the associated uncertainty components, the optical fiber will be tested in a real environment attached to the permanent seafloor observatory OBSEA[2].

2. EQUIPMENT

The following equipment will be used in the study.

2.1. Optical fiber

Two different designs of optical fibers will be deployed in the sea. Both of them will be based on the introduction of Bragg gratings (FBG) along the fibers to perform the temperature measurements at several depths, allowing the measurement of the sea temperature profile, as well as, the sea surface temperature.. The first one, named as profile fiber, will be used to measure the sea profile temperature by means the temperature measurements at different depths in the sea.The second one, named as control fiber, will be use to establish and measure the drifts of the profibe fiber as well as the drift of the thermometers located in the permanent seabed station, CTD systems. A deeper description of the fibers is given in the section 4.

Fiber Bragg gratings have been chosen as temperature sensor element due to their high resolution and reliability, their low fragility and drift, as well as, the low pressure influence. This last point is a critical factor in case measurements are needed at deep points in the sea. The FBG will have a diameter of 7 mm ,, with a reflectivity of 85% and a typical bandwidth of 0.23 nm. The FBG are centered at different wavelengths to differentiate them when measuring with the interrogator equipment. A typical relation between temperature and wave length is given in eq .(1).

$$T = C_3(\lambda - \lambda_o)^3 + C_2(\lambda - \lambda_o)^2 + C_1(\lambda - \lambda_0) + C_0$$ (1)

Where λ is the wavelength measured by the FBG interrogator, λ_o is the central wavelength of the FBG at 20 ºC and C_i are constants values that will be fixed in the calibration of the FBG as a thermometer.

The FBG will be calibrated in the temperature range (-20 ºC to 40º C), where a linear equation could be proposed and determined without making big errors. Anyhow, the uncertainty temperature calibration as well as the possible temperature errors will be analized as a function of different temperature calibration equations with different number of coefficients.. In case of linear fit, the expected slope (C_1) is 0,1 ºC/pm.

$$T = C_1(\lambda - \lambda_0) + C_0 \qquad (2)$$

The wavelength response of the FBG will be measured by mean an interrogator µMicron Optics Bragmeter SM125. This interrogator is based on a tunable fiber Fabry-Perot filterand, it has a resolution of 0.1 pm and a scanning rate of 1 sample per second.

The optical fiber has to be protected from the sea corrosion, pollution and sea-life (bio-fouling). Thus, a protective tube will be design and manufactured where the FBG will be located. The material of protective tube will be selected considering that such material presents a mechanical strength and chemical resistance high enough to avoid its damage under sea environment. On the other hand, the thermal response of the protective tube will have to adecuate to perform reliable measurements of the temperature sea variations.

Other factor to be considered in choosing the material is the heat conductivity of the protective tube, which on one hand, it has to be low enough in order to avoid wrong temperature measurements at points close to sea surface as well as the influence of the sea layers temperature adjacent to measurement points and, on the other hand, the heat conductivity has to be high enough to allow the fiber Bragg gratings is at the same temperature as the sea in the measurement point.

Preliminary designs and tests have been carried out to study the influence of the protective tube material, using teflon and polyethylene (PE) for a polyimide jacketed fiber. It has been observed a different temperature response as a function of the protective tube material.. As it was expected, the Bragg grating variation temperature is smaller when the protective tube material is Teflon than when it is polyethylene (PE). (9 ºC for teflon and 16 ºC for PE).

Additional test will be performed with polyaryletherketone (PAEK) as a material proctetive tube due it seems this material has a better behaviour against scaling and bio-fouling.

2.2. OBSEA

The OBSEA underwater observatory is located on the seabed, at 20 m sea depth, close to the coast of Vilanova i la Geltrú (Barcelona, Spain), in a fishing protected area.

The connexion between the OBSEA underwater observatory, as well as adjacent devices, and the laboratory facilities, located 1 000 m inside the coast, is by mean 4 km of cooper wire. This implies that, on one side, the underwater observatory is directly electrical power supplied trom land with up to 3.6kW and, on the other side, it allows a high bandwidth communication link of 1 Gbps. The main advantage of high bandwidth communication is that the interchange of information between laboratory and observatory is in real time, surpassing one of the drawbacks of battery powered systems. The implemented communication solution is an optical ethernet network that continuously transmits data from the oceanographic instruments to the laboratory, allowing the monitoring and storage of multiple parameters data in real-time and a better control, manage and checking of all possible alarms in the underwater observatoty..

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3. CALIBRATION OF OPTICAL FIBERS THERMOMETERS

The EMRP ENV58 project establish that the calibration of the distributed temperature sensors based on FBG will be carried out in two steps. Firstly an optical calibration will performed and secondly the fiber will be calibrated as a thermometer.

3.1.Optical calibration

The optical calibration the FBG needs the previous traceable calibration of the FBG interrogator in order to calculate the individual constant of the FBGs.

The calibration of the FBG implies to the determination of the measurement errors of the interrogator when reading the FBG wavelength, following the calibration procedure ans technique developed at IO-CSIC [3]. In the uncertainty evaluation all the influence quantities are considered and evaluated. This evaluation will be performed following the requirements expressed in the Guide to the expression of uncertainty in measurements m guide [4].. The preliminary results of this calibration are shown in Fig. 1

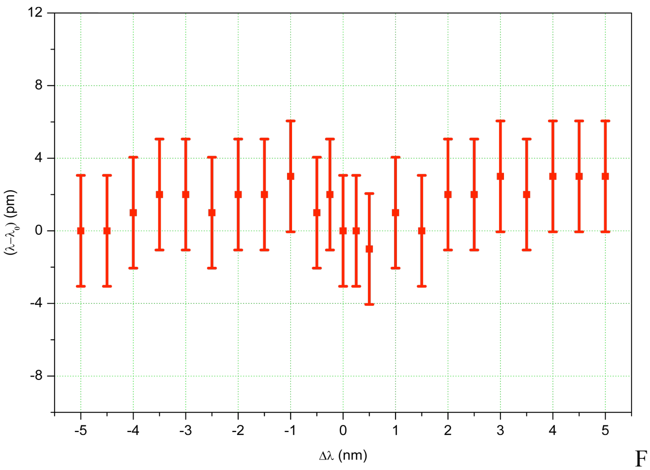

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Fig. 1. SM-125 calibration preliminary results.

The results show an uncertainty of ±3 pm (k =2) or ±0.3ºC in the calculated temperature. It was considered that this so high uncertainty is not adequate for the purpose of this project so further improvements will be developed regarding the optical references in order to achieve uncertainties lower than ±0.2 pm (±0.02 ºC). Then the calibration of FBG as a thermometers will be carried out at CEM with traceability to ITS-90..

3.2.. Calibration as a thermometer

The use of optical fibers inside the EMRP project "ENV 58. Metrology for essential climate variables" has two different purposes. On one hand one fiber will be designed manufactured, calibrated and characterized to analyze the drift of the temperature sensor located the submarine observatory OBSEA, CTD; And on the other hand, a second fiber will be designed, manufactured, calibrated and characterized to measure the sea temperature profile and the sea surface temperature. To reach these objectives traceable calibrations to ITS-90 with reliable uncertainty calculation of the optical fiber as thermometers and the CTD will be carried out at CEM. The calibrations will be performed in a water stirred bath, by comparison to Platinum Resistance thermometers, calibrated in fixed points and with traceability to ITS-90. With these facilities an expanded uncertainty (k =) of 0,05 ºC is expected, but the final calibration uncertainty will depend on the behaviour of the instruments to be calibrated.

Due to the huge dimensions of the CTD and the optical fibers, it was needed to design and manufacture a new water stirred bath of high dimensions as well as to perform its characterization by means the determination of the stability and the uniformity associated. This designed bath allows the calibration of big temperature sensors in the range (5, 50) ºC, with temperature stability and uniformity of 0,01 ºC. These characteristics implies a calibration expanded uncertainty (k =2) of 0,05 ºC. Further works in the bath design are needed in order to improve the stability and the uniformity, allowing in this way a lower uncertainty calibration of the temperature sensors. The uncertainty calculation was performed following the recommendations established in [4]

Initial calibration of one of the CTD system was performed, using the previously described bath as a isothermal medium. The used standards, whith traceability to ITS-90, were two platinum resistance thermometers (Pt-100) as standards. The uniformity of the water temperature in the calibration was monitored by means the use ot two thermometers, as well as, the control of the drift of the standards during the calibration procedure. The reading of the platinum resistance thermometers were performed by mean the resistance bridge ASL F-700, with traceability to Spanish national standards.

Preliminary results of the CTD calibration are showed in Fig 2.

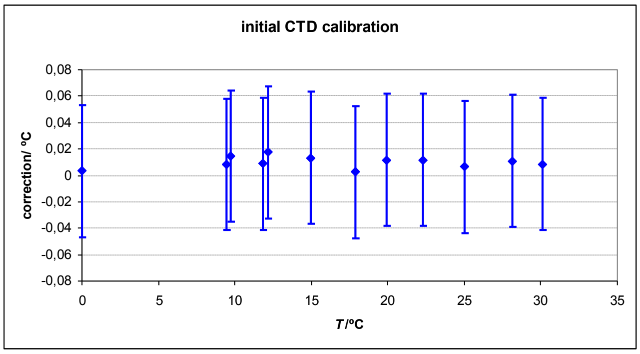

Fig 2. Initial calibration of the CTD at CEM

4. DEPLOYMENT

The experimental deployment under the sea consists on the placement of the two optical fibers, previously described, one with few gratings and working as control fibre and the other one with more gratings working as profile fiber and in charge of measuring the sea profile temperature and the sea surface temperature. The Fig. 3 shows, the zero (origin) of the fibers is fixed in the middle of the buoy, in principle the sea surface. The control fiber has 4 measure points located at (-50, 50, 1000 and 4000) cm from the zero, meanwhile the profile fiber has the measure points at (-50, 0, 2, 5, 10, 50, 100, 500, 1000, 2000 and 4000) cm from zero.

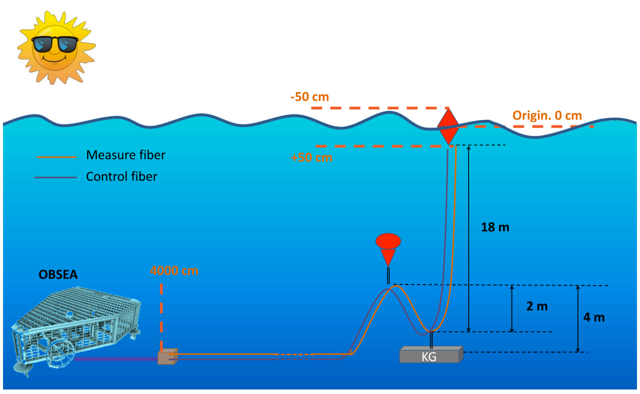

Fig. 3.Schematicof the connections underwater

The Bragg grating interrogator is connected to OBSEA, both to send the data and to receive energy.

An schedule of the activities that will be carried out are shows in Table 1:

Table 1. Detail for set up, study and evolution of theexperiment

Date	Activity
March 2016	The CTD SBE16 will be calibrated by CEM
April 2016	Deployment complete
May 2016	Change of the control fiber for another one.
July 2016	Change of the control fiber for another one.
October 2016	Change of the control fiber for another one.
May 2017	Extraction of the system to evaluate the state of the equipment

During the whole process the data will be controlled to detect any possible drift or any issue that might arise. This way the researchers can repair or take actions accordingly.

5. CONCLUSIONS

The aim of this research is to use an optical fiber like a distributed thermometer, so as to be able to make many measurements simultaneously and with their uncertainty associated.

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