Strain and Temperature Remote Sensing of Concrete Structures Using Photonic Sensors

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ABSTRACT

A remote sensing system for concrete civil structures is presented. The transducers used are based on Fiber Bragg Gratings and exhibit the capability of simultaneously measure both temperature and strain. The sensing system can be controlled remotely form any place in the world via Internet and/or mobile telephony. The system will allow the long term monitorization of the structure.

Keywords: Fiber Bragg Grating, Photonics Sensors, Remote sensing, Concrete structures, Strain and Temperature

1. INTRODUCTION

The long term monitoring of strain and temperature in concrete structures plays a key role in the determination of its structural health. Sometimes these concrete structures happen to be in far places so, in order to accomplish the monitoring, it is necessary to travel for long distances. It is in such cases in which remote sensing is most desirable.

With traditional means it is not possible to carry out a long term monitoring, because permanent and lasting transducers cannot be installed. That is a problem because usually with traditional techniques the monitoring is made only during the load test and it is not possible to know, during the lifetime of the structure, which its state is. With a long term monitoring it will be possible to know whether the behaviour of the structure is correct and, in the negative case, program the actions necessary to fix the structure and, subsequently, check that the actions made have been effective. That would allow saving in unnecessary costly actions that presently are being made in order to assure a well behaviour of the structure

In the last years the use of photonic sensors in civil structures has increased [1-4]. In the present paper, a sensor system that allows for this long term monitoring with the additional capability of remote operation is presented. The transducers used are based on Fiber Bragg Gratings (FBG) and they are able to accomplish simultaneous strain and temperature measurements. This photonic transducers exhibit, when compared with traditional methods, some important advantages, such as electromagnetic immunity, wavelength multiplexing capabilities, or significant complexity reduction in the wiring. The measurements obtained with the sensor system described herein are stored in an in-situ data base that is able to be remotely queried, via the Internet and mobile telephony. Thus, the remote sensing is possible and the measurements can be easily read in real-time in the office or in any other place in the world.

The structure of the paper is as follows: in section 2 the transducer used is presented, in section 3 their installation in a real concrete civil structures, a bridge, is described, in section 4 the remote sensing system and its possibilities are explored, in section 5 the experimental measurements during the load test of the bridge (made remotely) are presented, and, finally, in section 6 several conclusions are drawn.

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2. TRANSDUCER

Transducers based in Fiber Bragg Grating (FBG) are used among other applications for the sensing of concrete structure. As it is know the Fiber Bragg Grating are sensitive to both temperature and strain [5-7], so it is necessary to discriminate between these two parameters in order to have accurate measurements. There are solutions for the discrimination, but in this case the one selected for the transducer was the technique that is the simplest and most straightforward: the use of two FBG with different Bragg wavelengths [8,9]. One of them will be isolated from one of the both parameters, and thus it will be sensitive only to the other parameter, acting as a reference. The other FBG will be sensitive to both parameters and by using the measurements obtained with the reference FBG, the second parameter will be discriminated.

These transducers were designed to be embedded in the concrete structure without further protection, so it is necessary that the body of the transducer is hard enough to protect the fiber with the FBG. The material of which the body of transducer is made of must be as compatible as possible with the concrete. In this case methacrylate was the chosen material. On the orther hand the geometrical design must allow the traction/compression force of the concrete to be transferred undistorted to the FBG. This is achieved by making two wider heads at both ends of the transducer's body.

As has been previously said, inside the transducer there are two FBGs in the same fiber with different Bragg wavelengths. The first one is glued in the middle of transducer's body. The other one is let loose, so it is only sensitive to temperature and, therefore, it is used as a temperature reference in order to compensate the thermally-affected strain measurements from the fixed FBG. A diagram of the structure of the transducer is shown in figure 1.

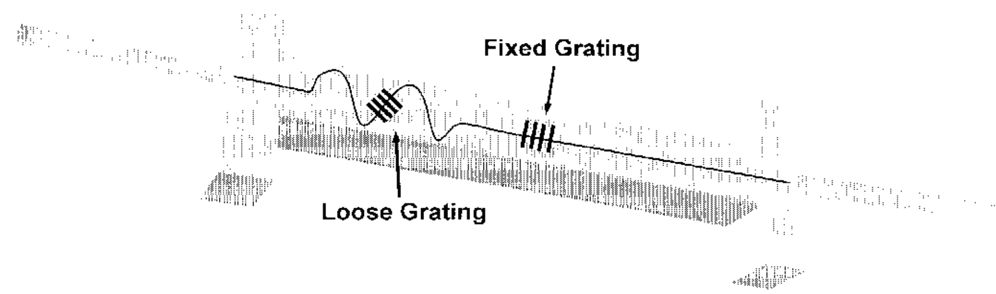

Figure 1.Diagram of the structure of the embeddable transducer

As fixed FBG is glued to the body of the transducer, it is very important to choose a glue that guarantees a perfect strain transference from the body to the sensing FBG. After carrying out some experimental works, an special cyanocrilate glue was employed.

Before a real use of these transducers would be possible, it was necessary to characterize them. As the transducer was meant to measure both strain and temperature, two different characterizations, one of temperature and other of strain were accomplished. With the first one the temperature sensitivities of the two FBG are obtained, being that of the FBG glued to the transducer's body around ten times bigger than that of the loose grating. This increment is due to the added up effects of Bragg wavelength thermal shift and methacrylate thermal expansion. Thanks to this induced difference in the thermal sensitivities of both FBGs, discrimination between strain and temperature could be carried out even though the loose grating was not perfectly isolated from strain. The temperature characterization was accomplished using a climatic chamber Hygros-15, and it consisted on subjecting the transducers to different thermal cycles. To perform the strain characterization a machine that is used to test the resistance of materials was employed.

The result of one of the characterizations is shown in figure 2. It represents the change in the wavelength reflected by the FBG with respect to the stretching force between the heads of the transducer. Young's modulus of the transducer must be used in order to obtain the strain from the applied force.

The slope of this graphic is the strain sensitivity of the transducer. Note that for the loose FBG this slope is null.

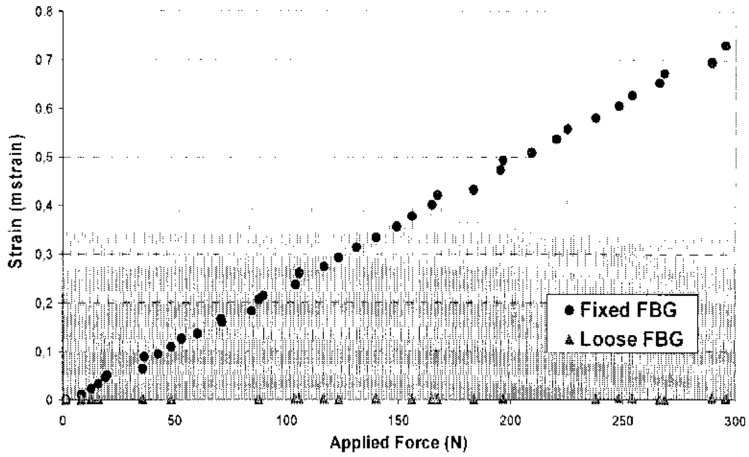

Figure 2.Graph of strain calibration of a transducer

3. INSTALLATION

The transducers have been installed in *Las Navas* bridge in the *Autovía del Cantábrico*, a new highway near *Cabezón de la Sal (Cantabria, Spain)*. The transducers were installed in critical parts of the structure, which were decided by experts in civil engineering. Since this is a symmetrical and repetitive structure (it is formed by ten identical sections limited by two piles each), in order to understand the behavior of the structure it is enough to monitor only two slices: one placed just on top of one pile and the other in the middle point between two consecutive piles. Finally 42 transducers have been installed in the bridge with the distribution shown in the figure 3.

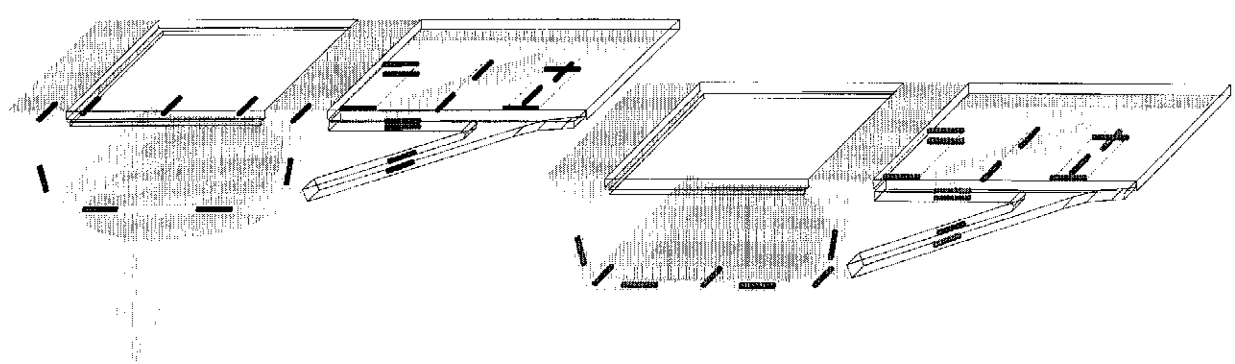

Figure 3.Distribution of transducers in the two slices monitored

In installations as big as this one, several precautions must be regarded. Civil structures as bridge cannot be built at once, but they are constructed in phases. This means that whenever one section of the structure is ready for the transducers' installation, other section is being built. There is a lot of activity around the installation place: lots of people soldering, cutting iron rods, hitting the structure to accommodate different ducts within the armor, etc. All the above multiply the risk of having a failure in the sensor system caused by a break in the channel (in such an environment a fiber optic channel is very likely to be cut if no special attention is been paid), or by excessive attenuation (like that induced by two iron rods pinching the channel), or by direct damage to the transducer's body. This implies that it is very important the way the channel and the transducers are protected. Nevertheless it is very probable that, when interrogating, the loss of one or more sensing points appears. In order to minimize these losses and their effects there are several recommendations that can be followed: first of all, and the most important, the different fiber branches containing the transducers should be accessible by their two extremes, and, secondly, these branches should not comprise a high number of transducers. The first recommendation increases the system's reliability because supposing the channel were broken in one of its middle points, all the transducers would still be accessible either by one extreme or the other and, thus, no loss of information would take place. The second recommendation tries to minimize the number of transducers lost in case the channel results broken in two or more points. Moreover, as the shorter the channel length the shorter the probability of being damaged, it also helps to increase the global system's reliability. Thus, in every branch there were only 3 transducers, and all of them connected to an optical switch in order to be able to automatically interrogate all the sensors using only one interrogation unit. A scheme of the branches and their connections to the optical switch and to the interrogation unit is shown in figure 4

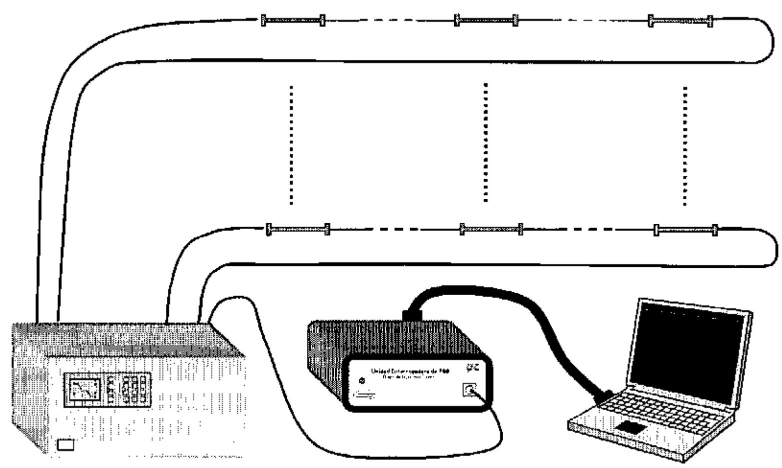

Figure 4. Scheme of connections of branches.

During the installation a special attention must be paid to the collocation of the transducers. It must be in the correct position, as much aligned with the structure as possible, because if for example the transducer were installed with some inclination, the measure of strain would be affected. So the transducers were installed using as reference and support the metallic structure, but in such a way that its deformation did not affect the strain measurement of the transducer. The metallic structure was also used too to provide extra protection to the transducer. In figure 5 a picture of a transducer attached to the metallic structure is shown.

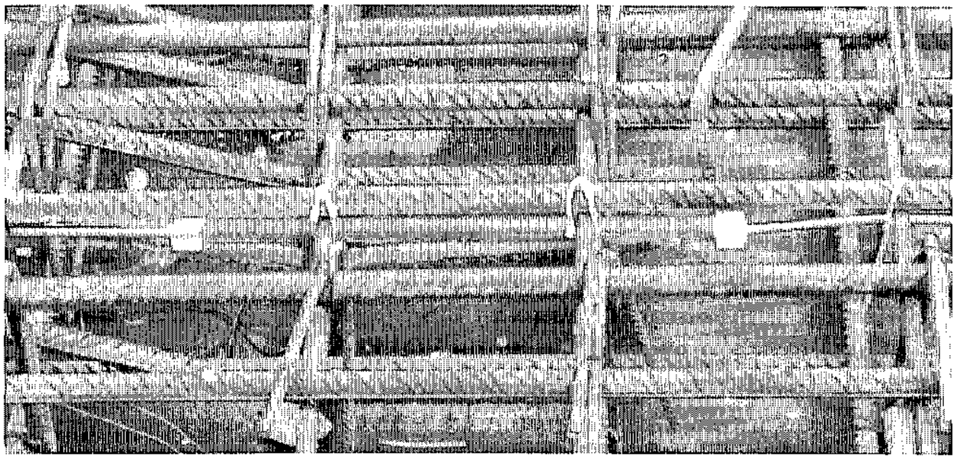

Figure 5. Photograph of a transducer attached to the metallic structure.

4. REMOTE SENSING

One of the attractiveness of this sensing system is the possibility of having, in real time, in any part of the world the measurements of strain and temperature of the civil structure. To accomplish that goal it is necessary to have an interrogation system able to remotely receive orders and send data.

The first step for obtaining such a system is necessary to have an interrogation system able to extract the wavelength encoded information measured by all the transducers installed in the civil structure. As has been previously shown a complex civil structure will need a lot of transducers distributed in several branches, so the interrogation of all transducers is not simple. All branches are connected to an optical switch, so it is necessary to know exactly which transducers are in every branches. Since the interrogation system must know in every moment the transducers that are being interrogated. Custom software able to control both the optical switch and interrogation unit was made. This software must be configured prior to operation for every civil structure, indicating how many branches are connected to the optical switch, in which channel is each transducers, etc. So the interrogation of the transducers will be time-multiplexed: the optical switch will periodically change the channel and the software will identify the transducer being interrogated in every moment. Al measurements are stored in a data based for the post-processing.

The second step is to make this information accessible from any place in the world, that is make remote sensing possible. There are several possibilities but the best solution is to use one that is very spread and cost efficient. In this moment the two technologies that join these characteristics in a highest degree are the Internet and mobile telephony. With the Internet there are a few solutions but the implementation of a web server in the computer that controls the interrogation system was the one chosen. So this computer will be the host of a web page that is able to read the data from the data base in which the interrogation system has previously saved the measurements. This page will be accessible, after an autentification of the user, from any computer, PDA, etc, connected to the Internet previously.

The web page has a lot of options. For example the user can select it to look like the software that controls the interrogation system. In this operating mode the user can choose, either graphically or by the name, the transducers to monitor. He can read data from past time o see it in real time. The user can also configure the interrogation system. Another important feature is that the user can program some alarm that provokes that the interrogation system send an e-mail to the user when something special happens, like a transducer not being able to be interrogated, or the strain and/or temperature of a transducer being higher than a programmed value. An example of the web page in the figure 6 is shown.

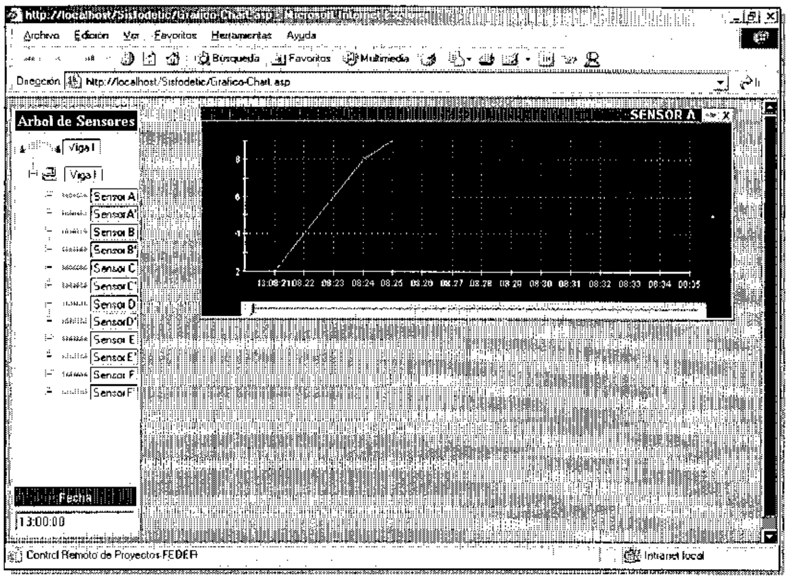

Figure 6. Web page of the interrogation system..

Sometimes it is not necessary to have and exhaustive control of the civil structure like the one give by the web page, but only a general supervision is required or the alarm is very important and cannot wait for the user to read the e-mail, or the user want to change something in the configuration of the interrogation system and he cannot connect to the Internet. To give solutions to these situations the system has the possibility of been controlled via a mobile phone. The computer that controls the interrogation system is connected to a mobile phone and, with a custom software, it is able to read the sms messages that the phone receive, interpret them and send an order to the interrogation system. The interrogation system can reply the sms with another sms containing the information demanded by the user. So, in resume, an user with a mobile phone can send a text message (sms) with a special syntax to demand some data (strain, temperature, etc) or to configure the interrogation system and it will reply to the user with another sms to confirm the change or to serve the required data.

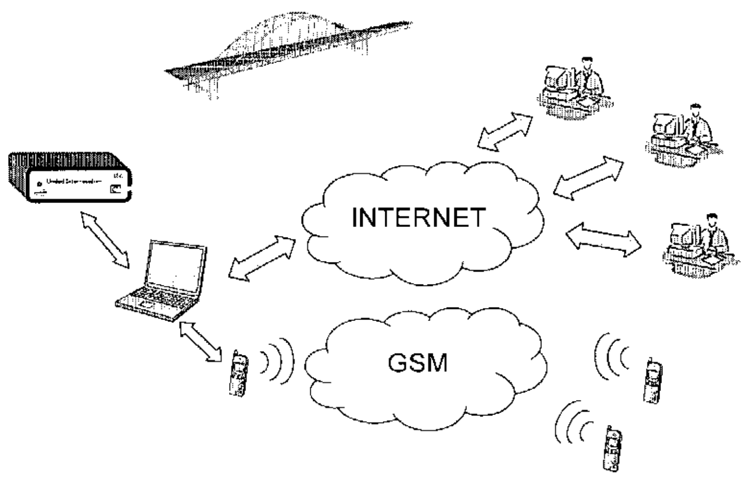

Figure 7. Scheme of remote sensing by the Internet and\or by GSM

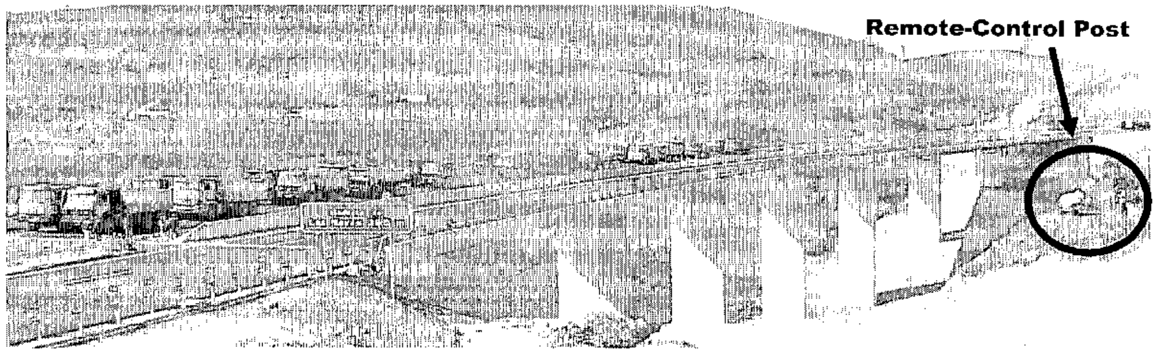

Figure 8. Photograph of a remote sensing during the load test

5. EXPERIMENTAL MEASUREMENTS

The remote interrogation capabilities of the system have been checked during the load test of bridge. The load test consisted in placing some trucks on the bridge with different configurations, called hypothesis. In each of the hypothesis the trucks stayed still for one hour more or less.

During the load test the computer that controlled the interrogation system was not connected to the Internet, but to an intranet, that is it was connected via a wireless network with another computer. From the point of view of the remote sensing this is as if the computer were connected to the Internet.

This method is very useful during the load test because the FBG interrogation system is placed inside of the bridge, so it is better to be in the outside for security. The figure 8 is a photograph during the load test in which the trucks and the Remote-Control Post can been seen.

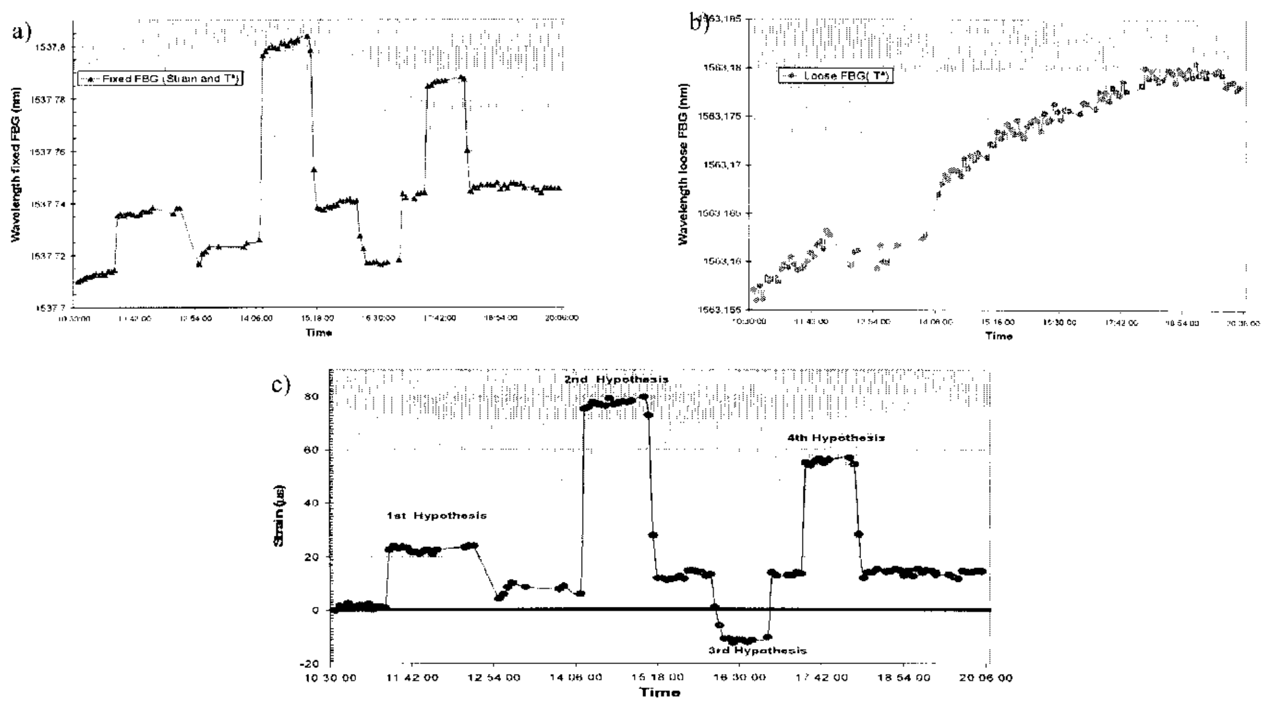

Figure 9. Data recorded during the load test: a) wavelength shift of the fixed FBG, b) wavelength shift of the loose FBG, c) strain measurement after compensation