Fibre optic sensor systems for structural health monitoring of concrete structures

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In this communication the development of fibre optic sensors for the structural health monitoring (SHM) of concrete based structures is reported. The sensors systems are very simple, work reliably and offer the possibility for multiplexing and operation in harsh environments. Applications such as long-term tilt and humidity sensing are briefly discussed.

1 Introduction

Fibre optic sensors are well suited for the structural health monitoring (SHM) of concrete structures since they can withstand the inherent harsh environments inside concrete structures. Another advantage is that several fibre optic sensors can be multiplexed and operated remotely over long distances. Thus, we developed a SHM system to monitor the conditions of sewerage tunnels using fibre optic sensors. We also investigate textile carbon structures with integrated fibre optic sensors for the SHM of carbon reinforced concrete elements.

2 SHM of sewerage tunnels using fibre optic sensors

There is a huge need of SHM systems that can continuously monitor the condition of sewerage tunnels since, for instance, in Germany about 20 % of the publicly owned and more than 40 % of the privately owned sewerage tunnels are damaged [2]. Current inspection systems for sewerage tunnels such as a camera based systems have the disadvantage that they only allow the inspection at regular intervals since they require the cleaning of the tunnel beforehand. Consequently, the application of fibre optic sensors could overcome this limitation.

In a first research project funded by the Bundesministerium für Wirtschaft und Energie (BMWi) a fibre optic sensor system for the SHM of sewerage tunnels was developed by the Hannover Centre for Optical Technologies in cooperation with the STFI and the companies Beton Tille, FiboTec, AOS GmbH and Textilwerk St. Micheln. The system consists of fibre optic humidity sensors, fibre optic tilt sensors and a remote interrogation system.

In order to detect leakages at the interface between two sewerage pipes and along the sewerage tunnel single-point fibre optic humidity sensors and a distributed leakage sensor were combined. A detailed description of this system can be found in [1], [2], and [3].

Fig 1 *Packaged FBG humidity sensor [3].*

The single-point humidity sensor was realized by coating a Fibre Bragg Grating (FBG) with Polyimide (PI). The PI swells in the presence of water and strains the FBG. This can be measured by a shift of the reflected Bragg wavelength. In order to apply the sensor in harsh environments an appropriate packaging based on a PEEK housing and a PTFE membrane were employed. The PI coated FBG and the packaging for the single-point fibre optic humidity sensor are shown in Fig. 1.

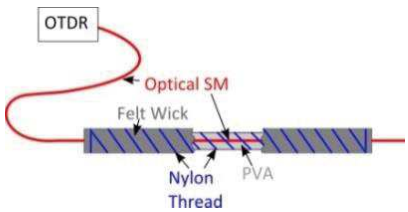

Fig 2 *Schematic of the distributed fibre optic leakage sensor [3].*

In order to detect leakages along a sewerage tunnel a distributed fibre optic leakage sensor was also implemented. The sensor consists of a PVA hydrogel rod, a micro-bender and a standard Single-Mode (SM) optical fibre (SMF28). The PVA hydrogel rod expands when exposed to water and presses the SMF28 against the micro-bender. The latter was realized by a helically twisted nylon thread and introduces micro- and macro-bends into the SMF28 fiber and, hence, leads to light attenuation. One example of a fabricated distributed fibre optic leakage sensor is shown in Fig. 2.

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Fig 3 *Installation of fibre optic sensors for the SHM of a sewerage tunnel.*

For the SHM of sewerage tunnels additionally a FBG based tilt sensor and an Optical Time-Domain Reflectometer (OTDR)-based interrogation system were developed. The FBG based tilt sensor was designed to measure the displacement of sewerage pipes. The OTDR-based interrogation system is based on a commercial device developed by FiboTec GmbH. A picture of the installation of the SHM system for long-term continuous monitoring of a sewerage tunnel is illustrated in Fig. 3. The fibre optic sensor system was installed in the municipal sewerage tunnel system in Meiningen, Germany.

3 SHM of carbon reinforced concrete structures

Reinforcement based on textile carbon structures allows the fabrication of resource-efficient and tailored (free-form) concrete elements. In a second research project funded by the Bundesministerium für Bildung und Forschung (BMBF) as part of the consortium "Carbon Concrete Composite – C^3" the HOT together with the STFI and the MFPA are investigating carbon reinforcement structures with integrated fibre optic sensors. The functionalized carbon structure can thus be used for both reinforcement as well as SHM of concrete structures.

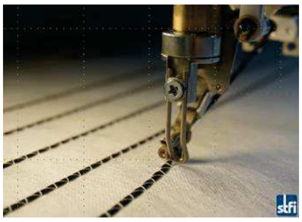

Fig 4 *Modified stitch machine for the simultaneous processing of carbon filament and optical glass fibre.*

To fabricate the functionalized carbon structure the STFI has developed an appropriate stitch technique. This technique allows the simultaneous processing of carbon filaments and optical glass fibres or optical fibre sensors to realize net based functionalised carbon elements. Depending on the application tailored carbon structures can be fabricated, i.e. several layers of carbon filaments with up to 50k rovings (corresponding to 3.200 tex) as well as very different net grids. A picture of the modified stitch machine for the fabrication of tailored carbon structures with integrated fibre optic sensors is shown in Fig. 4.

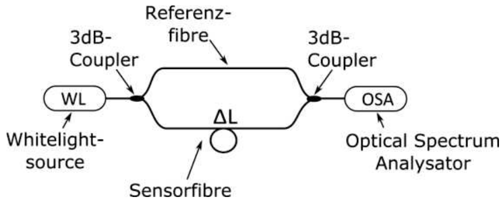

Fig 5 *Developed fibre optic MZ-interferometer for the sensor performance evaluation.*

In addition to the fabrication of the functionalized carbon structure the evaluation of the performance of the integrated fibre optic sensors is also important. In terms of applying the integrated optical glass fibre for SHM of the carbon reinforced concrete elements the evaluation of the force transfer between the carbon structure and the optical fibre as well as the sensor hysteresis and the sensor drift need to be quantified. To evaluate these parameters a fibre optic Mach-Zehnder (MZ)-interferometer was developed and utilized. The MZ-interferometer consists of a broadband light source (BBS), two 3dB couplers, a fibre optic reference and sensor arm as well as an optical spectrum analyser (OSA), as shown in Fig. 5. A length change ΔL of the sensor arm causes a phase difference between the light travelling in both fibre arms and, hence, a change of the interference pattern. Therefore, by observing the interference pattern the sensor performance can be evaluated.

4 Summary

A fibre optic sensors system based on humidity and tilt sensors for the SHM of sewerage tunnels was developed and implemented. Furthermore, textile carbon structures that are functionalised with optical fibre sensors are investigated for the SHM of carbon reinforced concrete elements. The reliability of both systems for long-term SHM are currently evaluated.

Acknowledgements

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