Smart electronic helper for long-term monitoring of bridges and building structures

Sergej JOHANN [1], Christoph STRANGFELD [1], David ZIMMEK[1], Matthias BARTHOLMAI [1]
[1] Bundesanstalt für Materialforschung und -prüfung (BAM), Berlin, Germany

Contact e-mail: Sergej.Johann@bam.de

ABSTRACT: Increasing traffic volume on the one hand and ageing infrastructure on the other hand have created many new challenges for maintenance and structural health monitoring of roads and bridges. In the past, many bridges and road structures have been neglected, often resulting in traffic congestion, road closure, and increased repair costs.

This research is concerned with the development of a system to improve the challenge of maintenance and early detection of damage, particularly moisture penetration and corrosion of steel reinforced concrete components. The objective is to develop a method that will also work after 30 years and longer. Many new IoT solutions are equipped with internal energy storage elements (accumulators or batteries) which are inappropriate here, since most relevant signs of concrete degradation occur after decades, where the functioning of such elements are more than questionable. The presented technology approach uses radio-frequency identification (RFID) and enables connectivity to sensors. It offers the advantage of an passive, completely independent energy supply without any energy storage components.

Since the system should be permanently embedded in concrete, it is crucial to develop a long-term stable device which is adapted to the environmental influences of the structure, e.g., long-term resistance in very alkaline environment of pH 13. In numerous experiments, the robustness of the system was tested and evaluated. Various tests with encapsulations to protect the electronics were performed, and for long-term validation different concrete specimens were instrumented with RFID-sensor-systems. Their operating time is now around two years and investigations for signs of fatigue and damage to the encapsulation and the electronics are ongoing.

1 INTRODUCTION

This paper deals with the development of a simplified procedure for the monitoring of bridges and building structures in order to detect possible damage at an early stage. Technologies with a longer service life are used to achieve the longest possible monitoring period. The developed solution approach is intended to extend the currently complex inspection method, which consists of a visual inspection of the object concerned, improve the inspection result, and reduce the costs for the inspection. Furthermore, the visual inspection should not only record the external damage, but also the internal damage, e.g., the corrosion of the reinforcement, whereby the systems cover an additional safety aspect. In order to develop such a system or method, this paper focuses primarily on the long-term stability, robustness, and reproducibility of the system. Preliminary work was carried out with regard to the encapsulation of the system, Johann et al (2016) and Johann et al (2017). The further development of the system with regard to its expandability is dealt with here. The results shown in Figure 5 result from the measurement series in which the encapsulation was still in the investigation phase. This then led to a corresponding improvement.

Chapter 2 describes the structure of the system, followed by Chapter 3, where the results of the long-term measurements are presented and explained. Chapter 4 summarizes the entire work and presents an outlook in Chapter 5. The references can be found in chapter 6.

2 OPTIMIZED SYSTEM DEVELOPMENT

2.1 Objectives

The main objective of this research is the complete and long-term embedding of electronic components in a concrete structure for structural health monitoring. In this case, energy and data transmission takes place via an electromagnetic field generated by a reading antenna using RFID (radio frequency identification) technology, which enables a completely passive system structure. As a result, sensors are supplied with energy in the vicinity of the point to be measured. By activating the sensors, measurements are started and values are generated, which are sent back to the reader device.

The communication interface (transponder) as well as the sensors were separated from each other and placed in such a way that a measurement is performed as accurate as possible and an optimal energy and data transmission can be guaranteed. Figure 1 shows the corresponding construction design, where it can be seen that the communication interface is placed as close as possible to the surface and that the sensors are located at the point to be measured. In this setup, however, the processes of road and bridge construction must be taken into account. The layers for stable road guidance are only built up gradually. In this case it can happen that the system is out of range and does not receive any or sufficient power supply and is therefore no longer responsive. In Germany, the thickness of the entire superstructure layers for road construction is between 12 cm and 75 cm, depending on the load class. Earlier investigations have shown that an installation depth of the transponder must not be greater than 10 cm in order to obtain a stable signal, Bartholmai et al (2016). However, the sensors should be placed in depth of the steel rebars, where corrosion may occur.

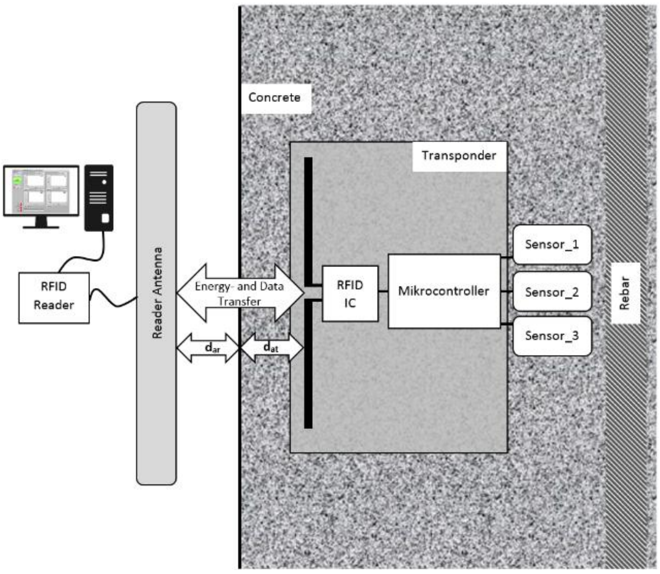

Figure 1. Concept of the measuring method.

2.2 *Embedded System*

The sensor system is optimized to a low-energy consumption because depending from the depth of installation only little energy from the transmitter is available to supply the entire system. For this purpose, components were selected which have a very low energy consumption. The sensor system have been designed in such a way that a large number of sensors can be addressed, and different parameters can be measured. The basic system is based on a RFID chip, an extremely low-power microcontroller, a DC/DC voltage regulator, a temperature and humidity sensor, as well as a necessary circuitry consisting of passive components. Figure 2 shows a schematic representation of a possible system structure with the associated extensions.

Figure 3 shows the structure of the encapsulation. The individual elements are intended to provide better protection against damaging influences. The encapsulation cover and the bottom part are glued watertight with PVC glue, the filter which is supposed to be the interface between the environment and the sensors is also glued to the housing with PVC glue. The electronics are enclosed with a protective layer of epoxy resin.

When connecting further sensors, which are led out externally, a corresponding encapsulation made of PVC (polyvinyl chloride) material is used for protection against the alkaline environment (pH 13). If the cables and the sensor are not protected, premature failure of the sensor or the entire system will result.

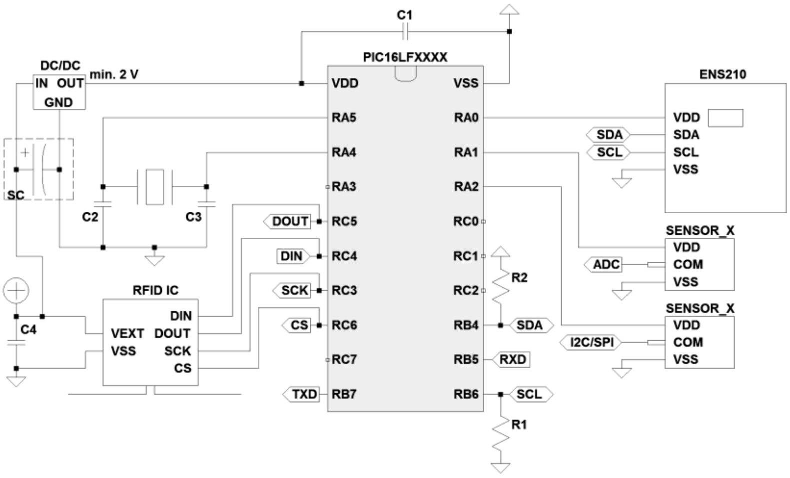

Figure 2. Schematics of the sensor system.

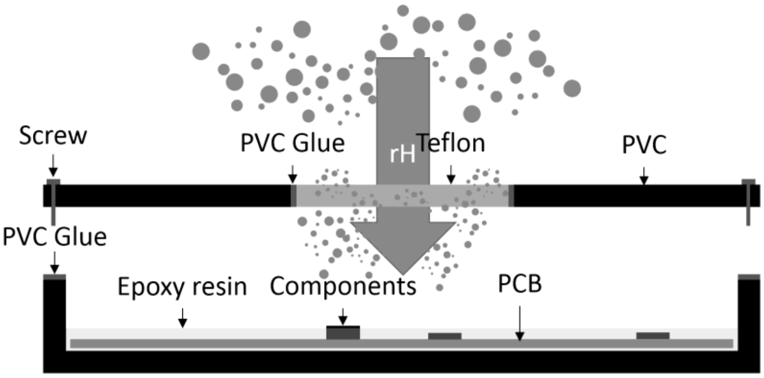

Figure 3. Protective measures for the fully embedded sensor system.

3 MEASUREMENT AND RESULTS OF THE PRELIMINARY VALIDATION

In order to create a constant environment, the four laboratory specimens made of screed were stored in a climatic chamber at 25 °C and 50 % humidity for the entire duration of the measurements. One specimen was instrumented with three different sensor systems: a UHF (Ultra High Frequency) RFID sensor system with a European transmission frequency of 865 - 869 MHz, a HF (High Frequency) RFID sensor system with a transmission frequency of 13.56 MHz, as well as a Bluetooth Low Energy Reference sensor system with a transmission frequency of 2.4 GHz and an active energy storage in the form of a battery. Figure 4 shows the arrangement of the sensor system in the casing of the test specimen, which was subsequently filled with screed. The sensor systems are positioned at the same height, resulting in a concrete cover of 6 cm above the sensors.

After the instrumentation and preparation of the test specimen, functional tests of the system were carried out by checking the transmission between the reader and transponder. From this point on, the series of measurements was started. The hydration process of the screed specimen as well as the effects on the instrumented sensor systems were monitored.

Figure 5 shows sensor systems of initial validations, which were encapsulated with a thermoplastic and epoxy resin. They have been removed and examined from a test specimen after approx. 10 months, Strangfeld et al (2016). Cracks in the protective layer of the epoxy resin were noticed, which caused the water to penetrate the sensor system and corrode the copper wires that make up the antenna. In addition, deposits have also been found in the humidity sensor, which can have an effect on the measured values. These results confirm the importance of material selection for long-term embedding in concrete.

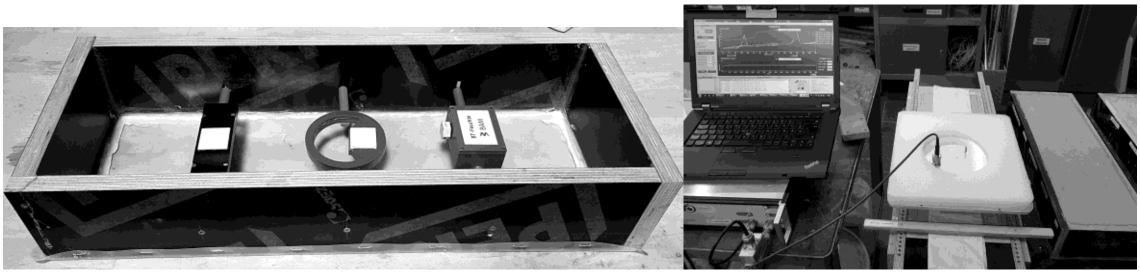

Figure 4. Instrumented casing of the described test specimen, left UHF, center HF and right Bluetooth. As well as the measuring method for the determination of the energy transfer.

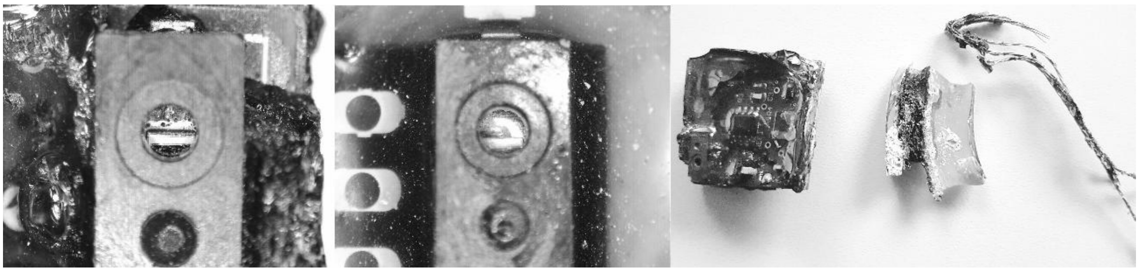

Figure 5. Examination of sensor systems after dismantling with thermoplastic casing and epoxy resin.

Using the PVC encapsulated systems, the following measurement results were obtained after more than 2 years and are shown in Figure 6. It can be seen that the presumed increase of the measurement signals occurred as a function of the hydration process. After reduction of liquid water due to hydration and evaporation, the signals gradually stabilize.

Due to an unknown event, the UHF sensor system can no longer be addressed. Thus the measurement was aborted at this point. However, the HF sensor system still shows a stabilized course. The results of the Bluetooth system were no longer recorded because the system was no longer responsive after a few weeks, probably due to the decreasing battery power. After a while, the measurements of the Bluetooth module became no longer relevant for this investigation. Therefore the method of an active system was successfully implemented in another project, Adao et al (2017). A possible cause for the failure of the systems is the capillary formation, as shown in Figure 7, which drew the water into the interior of the housing during the preparation of the test specimens and thus put the system into full saturation or destroyed individual components after some time.

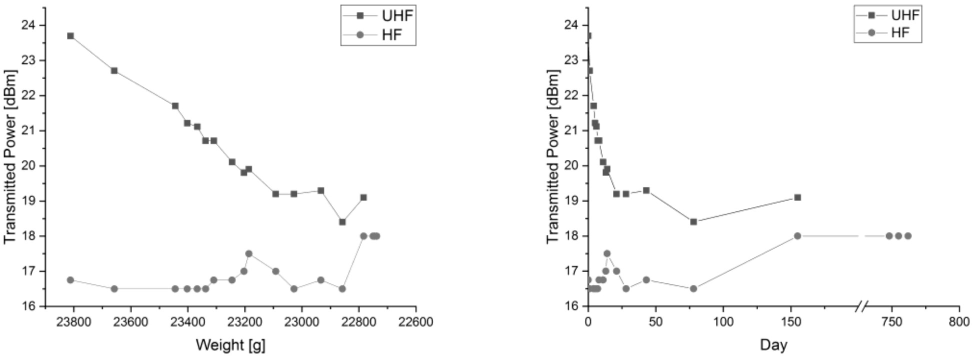

Figure 6. Measurement results of more than two-year measurement test, left: transfer power as a function of weight, right: transfer power as a function of the drying process

Figure 7. Capillary formation in the housing of the sensor system.

4 CONCLUSION

In summary, it should be noted that minimal cracks and incorrect selection of components can lead to premature failure of the systems. In order to prevent this, appropriate precautions must be taken to protect the system in the long term. The selection of the encapsulation and filter material poses a great challenge, as it is intended to provide protection, but is also a weak point (particularly the filter) for the sensitive electronics. The preliminary tests have shown that a glass filter cannot repel the water during the construction of the building structure and that a possible saturation due to water level or destruction of the system cannot be prevented.

Furthermore, a stabilization of the measuring signals could only be determined after more than 2 years, however, smaller laboratory test specimens were used, which were extended in real structural elements, depending on the size.

The optimized sensor system was also enhanced in terms of computing. An extremely low-power microcontroller manages the sensors, making it designed for versatile applications. This combination addresses the field of smart sensors in the building industry and has an enormous potential for long-term monitoring of building structures.

If sensor systems with energy storage components are used, the energy storage may already be largely exhausted or gone, when concrete damages occur, in contrast to a passive system. In conclusion, passive systems have the advantage, that they enable long-term measurements over decades without being tied to the battery life, which is very unstable with strong temperature fluctuations.

5 OUTLOOK

To a large extent, further steps have been taken to make the system more stable, robust and versatile. Further validation tests with the optimized sensor system in test specimens will be carried out promptly. One aim is to investigate Polytetrafluoroethylene (PTFE) as a suitable filter material and its behavior under stress in the concrete specimen.

Due to the versatility of the sensor system and the technological possibilities, further connections of sensors are possible. Current internal research and developments see a connection of sensors for pH value determination in concrete as a very good method to monitor the condition of the structure even better.

6 REFERENCES

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