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Study on wireless sensing for monitoring the corrosion of reinforcement in concrete structures

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ABSTRACT

The reinforcement corrosion has a serious impact on durability and safety of reinforced concrete structures. Based on radio frequency technology, the wireless sensor for the monitoring of reinforcement corrosion is investigated in this paper. The sensors are fabricated and experiments on the sensors are carried out. Experimental results show that it is feasible to determine whether the steel wire is broken or not by monitoring the resonant frequency of the circuit, and the sensor with spring switch designed in this paper can solve the problem of the resonant frequency missing of the sensor during the process of the steel wire corrosion. The encapsulation materials for the sensors are studied.

1. Introduction

The failure of the structures caused by reinforcement corrosion is a worldwide problem. In 2000, the collapse of the North Carolina speedway pedestrian bridge in USA is one of the serious safety hazards caused by reinforcement corrosion [1]. Therefore, the monitoring of the corrosion of reinforcement in concrete structures is an important part of health monitoring of structures. The real time monitoring of the status of the reinforcement corrosion can provide very important information relating to the actual damage of the structures, and protect the structures from the serious safety hazards such as the collapse of the North Carolina speedway pedestrian bridge in USA. And it can provide important basis for the assessment of the durability of the structures, the prediction of remaining service life of existing concrete structures and the strengthening and repairing of the structures.

Currently there are several sensors commercially available that are designed to aid in the early detection of corrosion in reinforced concrete [2]. For example, CMS system used in the Hun-Min viaduct works in Shanghai [3], and anode-ladder used in the Hangzhou Bay Bridge [4]. Unfortunately, the sensors are expensive, and the need to wire each sensor together also adds to the installation costs.

Bernhard and Heeltaps et al. of University of Illinois have investigated an embedded corrosion monitoring system in concrete bridge [5]. In the sensor, the ultrasonic technique is used to detect corrosion and the data is transmitted by broad band microwave antenna. But the use of ultrasonic technique increased the cost of this sensor system. Also, with the need for batteries, the sensors can work during the time period much short than the lifetime of the structures which they are designed to monitor. Engineers at the Johns Hopkins University have developed a smart sensor that is designed to provide data about corrosion status in the bridge deck [6]. This sensor can measure the concrete conductivity and the data of sensors is transmitted by wireless chip. University of Texas developed a kind of wireless sensor to monitor steel wire corrosion using radio frequency technology [7]. But the signal of this sensor is missing sometimes.

The mechanism of the wireless sensors for the monitoring of reinforcement corrosion based on LC circuit is investigated in this paper. The wireless sensor for the monitoring

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of reinforcement corrosion is designed and the experiment is carried out.

2. Designs of sensors

LC circuit is shown in Fig. 1, and the resonant frequency of the whole circuit is given by Thompson formula:

$$f = \frac{1}{2\pi\sqrt{L \cdot C}} \tag{1}$$

where L is the total inductance of the circuit; C is the total capacitance of the circuit. According to the Eq. (1), the change of the inductance or the capacitance of the circuit will lead to the change of resonant frequency.

As shown in Fig. 1a, a steel wire K is added to the circuit. When the steel wire is not broken, the total capacitance of the circuit is equal to the summation of the two capacitances ($C = C1 + C2$). When the steel wire is broken due to corrosion, the total capacitance of the circuit becomes $C1$. So the resonant frequency of the circuit depends on the state of the steel wire. Because the diameter of the steel wire is much smaller, the steel wire will break due to corrosion before appreciable corrosion damage has occurred in the reinforcement. As shown in Fig. 1b, a set of wires of different diameter are added to the circuit. The resonance frequency will change when each wire breaks due to corrosion. If the relationship between the diameter of the broken steel wire and the corrosion level of the reinforcement is obtained by experiments, the induced resonance frequency shift would determine the amount of corrosion of reinforcement in concrete when each wire breaks due to corrosion. Therefore the sensors with different diameters steel wires can be used to monitor a set of the discrete states of the reinforcement corrosion.

The right part of Fig. 1 is LC circuit, which is sealed except the steel wire and embedded in the concrete near the reinforcement to be monitored. The left part of Fig. 1 is the reader, which is fixed on the surface of the concrete structure. It is used to measure the resonant frequency of the sensor. When the reinforcement in the concrete is under corrosion, the steel wire is also corroded and will break, which causes a change in the resonant frequency of the sensor, and the signal of the reinforcement corrosion is transmitted from inside to outside of concrete. This technology allows the sensor to be free of an internal power source, which means that the sensors will be readable throughout the lifetime of the structure. So the sensor is wireless, passive and inexpensive.

According to the mechanism of the resonant circuit, the resonant frequency of the circuit can be obtained through

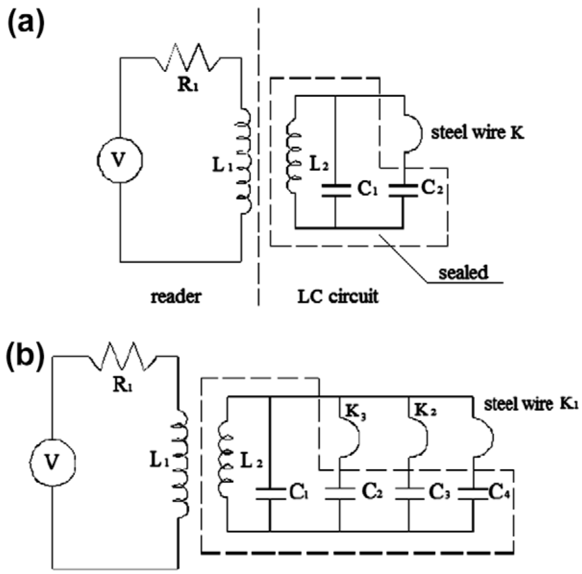

Fig. 1. Circuit diagram for sensor.

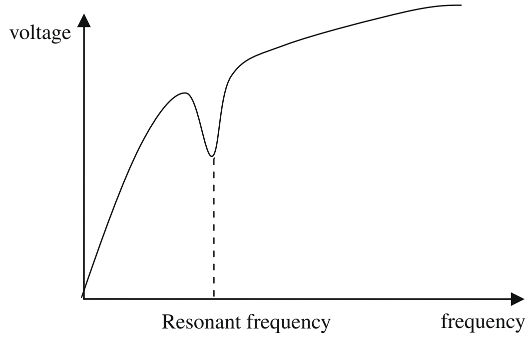

Fig. 2. The amplitude frequency characteristic curve of the voltage on the inductance.

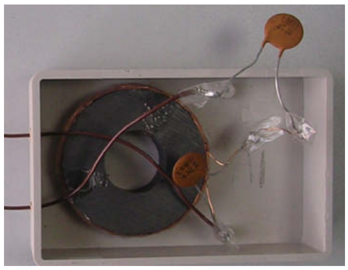

Fig. 3. Photo of the sensor.

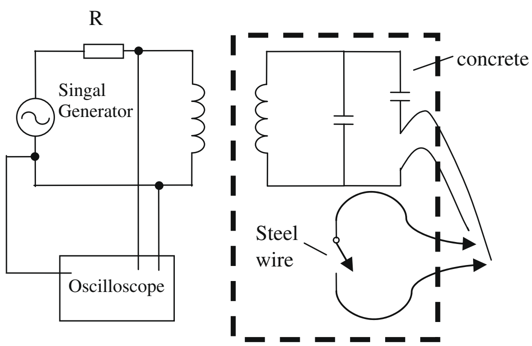

Fig. 4. The sensor and reader.