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# An instrument for detecting corrosion in anchorage zones of bridge cables using guided waves

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**Abstract**
Corrosion often occurs in anchorage zones of bridge cables which is a serious problem to the bridge safety. Moreover, accessing to an anchorage zone for corrosion detection is nearly impossible. An instrument for detecting corrosion in anchorage zones of bridge cables using guided waves is described. This instrument consists of a transmitter, a receiver, a power amplifier, a signal generator, a signal processing circuit, a power supply system and a software program. The instrument can detect corrosion in anchorage zones from the free length of cable and without removing the stainless steel sheath and the high density polyethylene coating. The corrosion (approximately 5% cross sectional area) in the anchorage zone of a parallel wire cable is detected using this instrument. The instrument has gained the favourable results in laboratory experiments and field applications since 2006.

**Keywords:** corrosion, instrument, guided wave, anchorage zone, bridge cable

## 1. Introduction

Cables are fundamental components of cable-supported bridges, such as suspension bridges and cable-stayed bridges. High strength parallel wire cables have been used for long span cable-stayed bridges throughout the world, such as Sutong Bridge in China, Tatara Bridge in Japan and Pont de Normandie in France. As the primary load-carrying members of cable-stayed bridges, the stay cables is one of the most important and crucial elements of the entire bridge. The anchorage zones are vulnerable due to local stresses or notches created by the anchoring device. When the coating such as the high density polyethylene (HDPE) cracks, the ingress of moisture will cause corrosion in anchorage zones [1-3]. The tension of cable leads to more severe corrosion problems than the no-tension condition [1-2].
In most cases, the stay cables are hidden from inspectors to prevent corrosion damage. Access to cables for nondestructive testing (NDT) is difficult, especially in the case of the anchorage zone. For practical application, the cables are dipped in the bridge deck. Some steel sockets are used to protect the cables on the deck, as shown in Figure 1. Access to the anchorage zone for NDT is very hard and the end of the cable is difficult to reach for the parallel wire cable. The ultrasonic waves are greatly attenuated by the epoxy resin and small steel balls. Moreover, corrosion tests by Hamilton showed corrosion inside unfilled epoxy resin wires, but no corrosion was found in the filled wires [2]. The area of most frequent corrosion occurs is in the sealing tube. If the anchorage zone could be inspected from the cable body, the attenuation of ultrasonic wave in the epoxy resin and the demand to access the end of cable could be avoided. Therefore, an effective NDT method for anchorage zones from cable body is required urgently to the safety of cable bridges. This paper describes an instrument for detecting corrosion in anchorage zones of parallel wire cables using guided waves from the cable body.

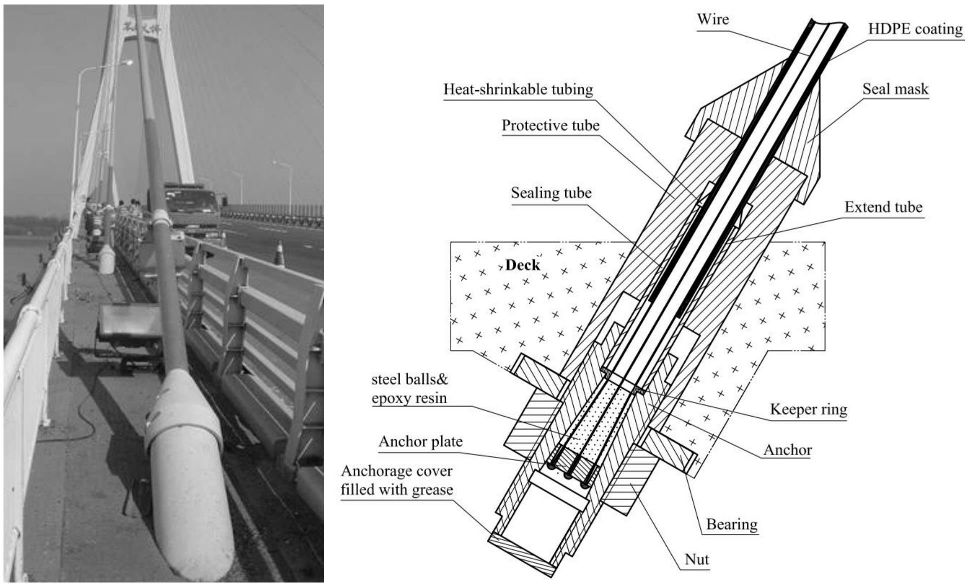

Figure 1. Stay cables installed in the bridge

## 2. Inspection instrument for anchorage zones of bridge cables using guided waves

The guided wave technology has been verified an effective NDT method [4-5]. As guided waves can travel long distance from the excited position with low attenuation, the technology is propitious to inspect hidden places. The echo will occur when the waves encounter corrosions. The condition of corrosions can be achieved by obtaining the echo waves. Several technologies are applied to generate guided waves, such as piezoelectric, laser, electromagnetic acoustic and magnetostrictive technology. The magnetostrictive technology can generate guided waves with large lift-off distance. Therefore the transducers could be installed on the body of cable to detect the corrosion in anchorage zones. The magnetostrictive technology generates guided waves in strands based on the Joule effect and detects guided waves based on the Villari effect [6]. Based on the above requirements and the principle of guided waves, the inspection instrument is designed as shown in figure 2. The instrument concludes transducers, the power circuit, the weak signal circuit, the power supply system and the software.

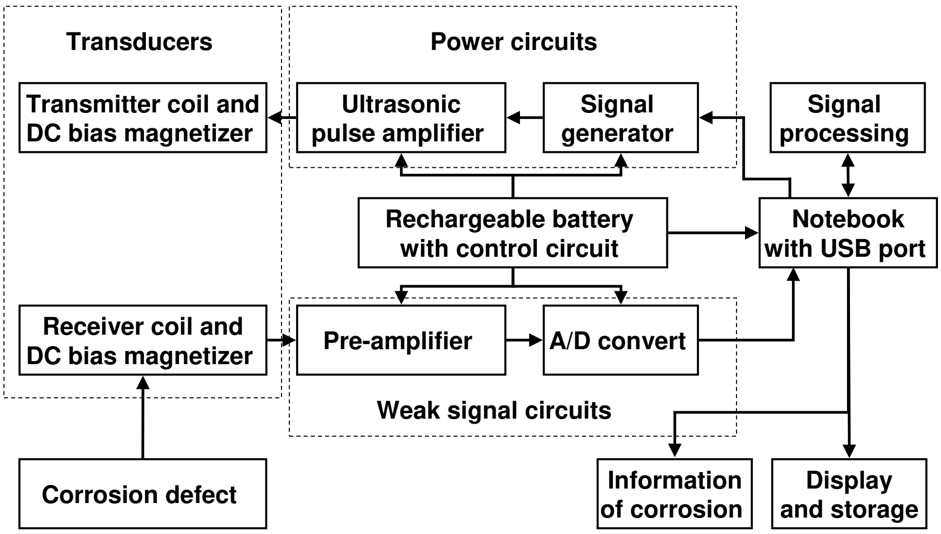

Figure 2. The inspection instrument for detecting corrosion of anchorage zones

### *2.1 Transducers*

Based on the Joule effect, the alternating current (AC) axial magnetic field need be occurred in the cables to generate the longitudinal guided waves. An open flat coil is applied to convenience for field applications. To cancel the second-harmonic generation and improve the coupling efficiency, the axial bias magnetic field is demanded. The magnetic field can be created by AC, DC, or permanent magnet. Rare-earth magnets (neodymium-iron-boron magnets) were applied in the sensor system to provide the bias magnetic field. The permanent magnet does not require additional power supply which is suit for the field application. The magnetizer concludes the permanent magnets and the pure iron. Similarly, the magnetizer is modularized for field applications. The different diameter cables are applied different numbers of magnetizers. The coil and the magnetizer were shown in figure 3. Based on the Villari effect, the induced coil need circumnavigate the strand to receive the echo wave. Similarly, the axial bias magnetic field is demanded. The receiving transducer is same as the transmitting.

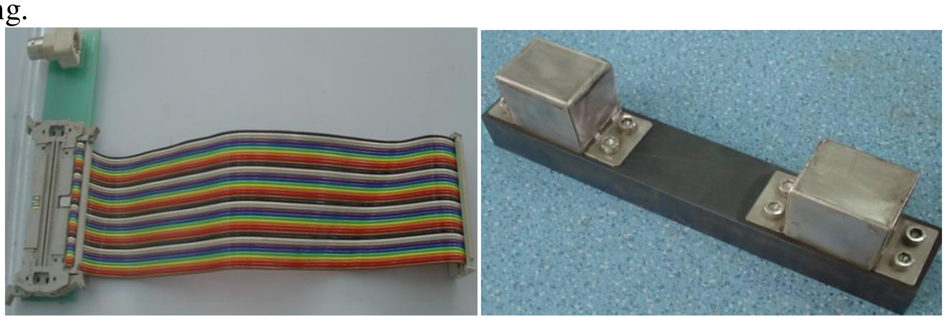

Figure 3. The transmitter coil and the magnetizer with open structure

### *2.3 Power circuit and weak signal circuit*

The power circuit provides high power energy with the special frequency to the transmitter which concludes the signal generator and the ultrasonic pulse amplifier. The signal provides by the power circuit with optional parameters, such as the frequency 5kHz-100kHz, the period 1~20, the power 1~10kW. The weak signal circuit is applied to amplify and filter the signal received by the receiver. The magnification of the circuit is 20-80dB with step 1dB. The frequency range of the band-filter is optional, such as 2kHz-20kHz, 10kHz-40kHz, 20kHz-60kHz, 40kHz-80kHz, 80kHz-100kHz. The A/D converter is applied to convert the analogue signal to the digital signal which is imported the notebook by the USB port.

### *2.4 Power supply system*

The energy of instrument is supplied by a rechargeable battery. As the power supply for the ultrasonic pulse amplifier, the signal generator, the pre-amplifier, the A/D convert and the notebook, the instrument can work 8 hours continuously in field.

### *2.5 Software*

The software is applied to control the sampling parameters, storage the data, process the signals, display the information of corrosions and so on.

### *2.6 Workflow*

Firstly, the transducers are installed on the cable body from the deck of bridges. Secondly, the signal generator which is controlled by notebook produces special frequency and period sine wave to the pulse amplifier. Thirdly, the high power signal up to 10kW is exported to the transmitter coil. Based on the Joule effect, the guided waves will be generated in the strands. If the echo waves from the end and corrosions in anchorage zones pass through the receiving coil, the voltage will be induced in the coil by the Villari effect. After amplifying and filtering, the analog-to-digital conversion signal is imported to notebook. The information about corrosions will be obtained by the signal analysis and processing.

## 3. Lab experiment and field application

The instrument was designed and built in 2006. Lab tests were completed in 2007 and the instrument was applied to detect anchorage zones of the suspension bridges and cable-stayed bridges in china, such as Junshan Yangtze River cable-stayed bridge and Runyang Yangtze River suspension and cable-stayed bridge. Lab tests and field applications have obtained the favorable results.

In the lab experiment, the parallel wire stay cable was a PES7-451 cable, with 180mm diameter, Φ7mm*451 wires, 11mm HDPE thickness. The corrosions were located at 890mm from one side end and 1000mm from another side end respectively. The corrosion of the left side was almost 5% cross section area loss and the right side was almost 10% cross section area loss. Figure 4 shows the schematic diagram of the experimental setup. Figure 5 shows the data obtained from the experiment setup as shown in figure 5. The echoes of the 5% and the 10% corrosions are clearly shown in the figure. The signal amplitude of corrosion 1 was larger than corrosion 2. The reason was that the echo wave of corrosion 2 propagated longer than the corrosion 1 in the cable body. The longer distance was about 1480mm which caused attenuation by the cable body. The result indicated that the method need set up the sensors near the anchorage zones. Because the sensors were installed on the cable body on the deck of the bridge, the distance was no more than 5000mm in the field application.

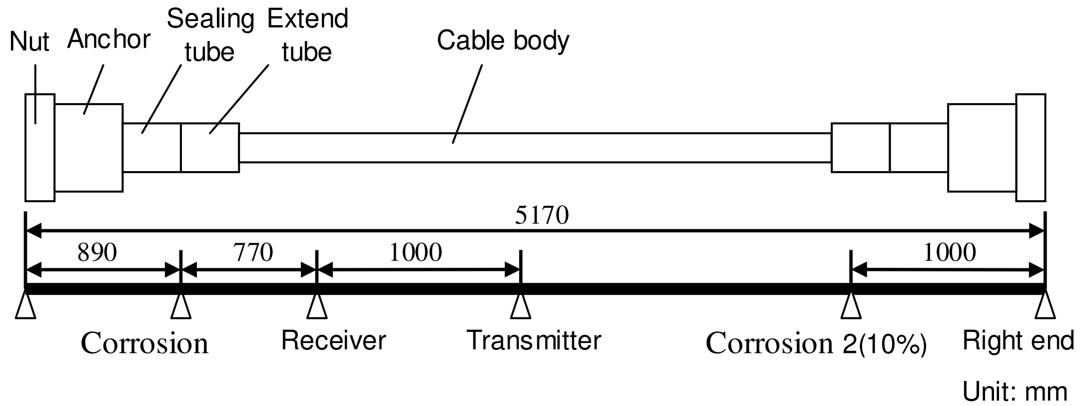


**Figure 4** Schematic diagram of experimental setup

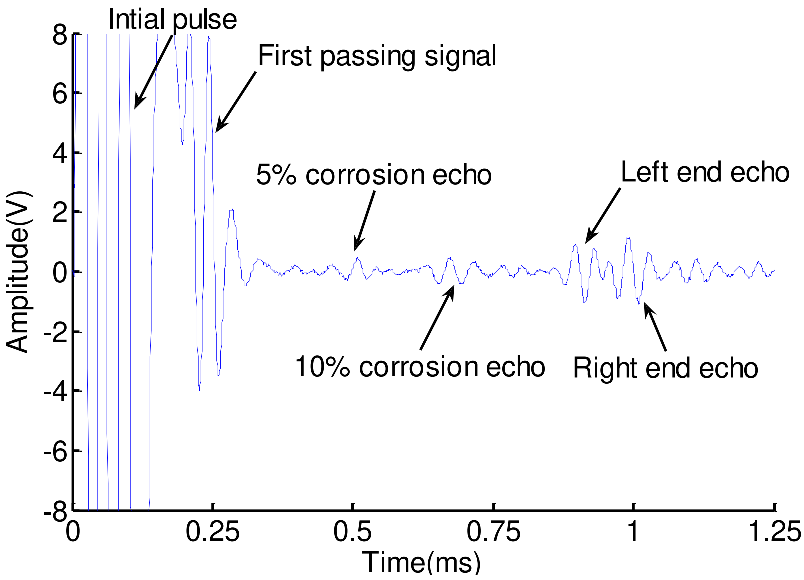


Figure 5 Data obtained in the experiment setup as shown in figure 4

In the field application, we detected the anchorage zones of cables from the deck. There were 2m length stainless steel sheaths on the cables. The transducers were installed on the sheaths directly. The photos of field applications are shown in figure 6.

(a) Cable-stayed bridge (b) suspension bridge

Figure 6 The photos of field applications

## 4. Conclusions

An instrument for detecting corrosion in anchorage zones of parallel wire cables based on magnetostrictive guided wave technology are described. The instrument could detect the corrosion in anchorage zones from the free length of cable and without removing the stainless steel sheaths and the HDPE coatings. Much information of corrosions could be obtained from the instrument, such as position, length and quantity. Moreover, the instrument could be used to detect corrosions the free length of cable, but the detection range is limited due to the high excited frequency. In general, the instrument supports the inspecting and maintaining of parallel wire cables to the cable-supported bridges.

**Acknowledgements**

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