Effective Guided Wave Technique for Performing Non-destructive Inspection on Steel Wire Ropes that Hoist Elevators

Peter W. Tse and J.M. Chen

Abstract The steel wire ropes that hoist elevators will eventually become rusted and then cracked as they always expose to air that contains high salinity content. A number of rope broken accidents occurred because of inappropriate maintenance that causes the ignorance of broken wires in a steel rope. Elevator ropes have very complicated structure as they are formed by twisted many small wires together to form a bigger rope. Such complicated structure creates difficulty to currently available non-destructive evaluation methods. To avoid the accidents, proper maintenance equipped with effective non-destructive testing method that must be presented. However, as of today, most of the elevator rope inspections are depends on human visual inspection. Such inspection fails to detect faults occurred in internal wires and even external wires due to the covering of grease on the ropes. The aim of this study is to introduce a new and effective technique based on ultrasonic guided waves for inspecting the faults occurred in internal and external wires. The experimental results demonstrate that the ultrasonic guided wave can detect the locations of broken wires and then determine the number of broken wires effectively. The experimental results also show that the PZT sensor is more suitable for working as a transmitter/emitter and the MsS is better working as a receiver. For grease covered ropes, the results show that the range of inspection distance will be decreased due to the attenuation of the reflected signal energy. Nonetheless, the reflected signal caused by the defects can still be clearly observed even the rope was covered by grease. Although the current results are promising, more sophisticated method must be developed so that the proposed technique can be applied to on-site ropes tests. The future research may include the development of optimizing the operation parameters of guided wave and the design of practical sensor for operating ropes.

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1 Introduction

The structure of Steel wire ropes/cables is complex, as they are formed by many twisted and inter-locked wires. A tested hoist wire rope (8 × 19S + FC) has a fibre core which is shown in Fig. 1. The wire ropes are widely used in elevators for hoisting or supporting heavy objects. An elevator bears heavy loads during daily operation. Day after day, loading and unloading heavy objects could make steel wire ropes/cables prone to severe defect. A saline and humid environment in particulate country areas escalates the wear on ropes and cables, which can lead to their sudden breakage. For instance, rope accidents have caused hoist lifts to sudden plunge to the ground, resulting in human casualties. To avoid that, several methods in existence today are applied for wire ropes/cables inspection. These methods include the use of magnetic flux leakage testing [1], human visual testing, and magnetostrictive testing [2].

The principle of the magnetic flux leakage testing method is to inspect wire ropes by using a high strength magnetic field that is moving along the wire ropes. If there are any defects occurred in the specimen, the leakage of the magnetic field will be detected by the transducer. Human visual testing method is the traditional rope detection technologies. It is mostly dependent on visual inspection by measuring rope diameter. The reduction in diameter illustrates corrosion, breakage and failure in a wire rope. Magnetostrictive testing is a method using magnetostrictive techniques. Magnetostrictive effect is caused by the permanent magnet circuit

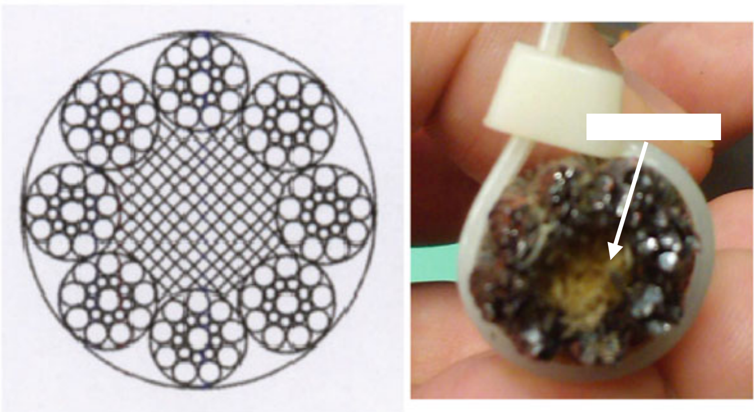


Fig. 1 Cross-section view of a hoist wire rope (8 × 19S + FC)

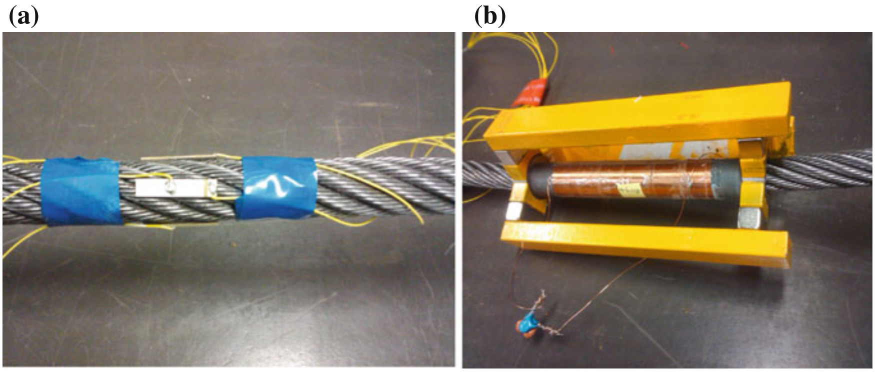
provided by the state of strain of a ferromagnetic and the dynamic magnetic field provided by hard sensing coil. The magnetostrictive effect will generate ultrasonic guided waves, which are elastic waves propagating in measured objective. The ultrasonic guided wave has advantages of high sensitivity, long-distance inspection with low attenuation, and line to line inspection. In addition to magnetostrictive testing method, a piezoelectric testing method based on guided wave technology is proposed for wire ropes inspection. The piezoelectric transducers (PZT) are made of length expander-type piezoelectric materials and distributed axisymmetrically, which ensures that proper modes are excited while generating guided waves [3], and this technology has widely been used in pipe inspection at present.

For all the abovementioned technologies, they have their own advantages as well as weaknesses. The weaknesses include difficulties in sensor installation, complications in analysing the reflected wave signals caused by defects occurred in the inspected ropes, and inconsistence in the results, etc. Nowadays, the techniques using ultrasonic guided wave are considered popular non-destructive testing (NDT) methods due to their long-range inspection abilities and high degree of sensitivity in detecting defects. The present chapter will focus on assessing the effectiveness of an ultrasonic guided wave technique on inspecting steel wire ropes that hoist elevators.

2 The Guided Wave Transduction System

2.1 The Types of Available Sensors

Although the ultrasonic guided waves have been applied for wire rope inspection, the design of an optimal sensor configuration is necessary in order to excite required wave modes that will minimize the complication embedded in the received guided wave reflected by different types of defects. As mentioned earlier, ultrasonic guided waves can be generated by magnetostrictive testing and piezoelectric testing methods. As shown in Fig. 2, two sensor configurations, namely the Piezoelectric Transducer (PZT) and the Magnetostrictive Sensor (MsS), were chosen as the sensors for emitting and receiving the guided waves when inspecting ropes. Two wave based measurements were applied in this experiment. They were pulse-echo and pulse-catch modes, respectively. In the pulse-echo mode, signals reflected from the defect edge were excited and received by the same transducer. Different from the pulse-echo mode, in the pulse-catch mode, signals were excited by the transmitter and received by the receiver.



The PZT sensor. The MsS sensor.

Fig. 2 The two sensor configurations used for inspecting ropes. **a** The PZT sensor. **b** The MsS sensor

2.2 The PZT Sensors Installed for Working in the Pulse-Echo Mode

The installation location of the PZT sensor in a 2.02 m wire rope is shown in Fig. 3. Based on our research findings [4], the PZT was working in a pulse-echo mode and the working frequency was set at 100 kHz. The gain for the receiver signal was about 40 dB. The peak amplitude of the "Echo from right end" was about 1 V. Meanwhile, the signal reflected from the left end (propagated about 2.88 m) and the echoes from both ends (propagated about 4.04 m) were received by the PZT. Figure 4 depicts the received reflection signal waveform by PZT sensor.

In Fig. 4, it shows one of the advantages of using the PZT is its high energy conversion efficiency. However, the PZT sensor must be pasted or pressed onto the wire rope surface, which restricts its application for real wire rope detection. Moreover, when the PZT sensor was working at the pulse-echo mode, the oscillation signals deduced by the wafer itself was overlapping with the received signal waveform especially at the beginning of the reflected signal waveform as shown in Fig. 4. Therefore, PZT sensor is more suitable for working as a transmitter/emitter, rather than as a receiver.

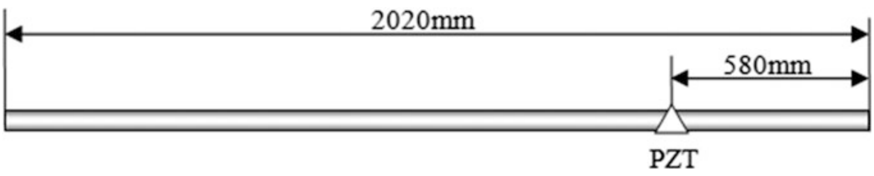


Fig. 3 The installation location of the PZT in the rope

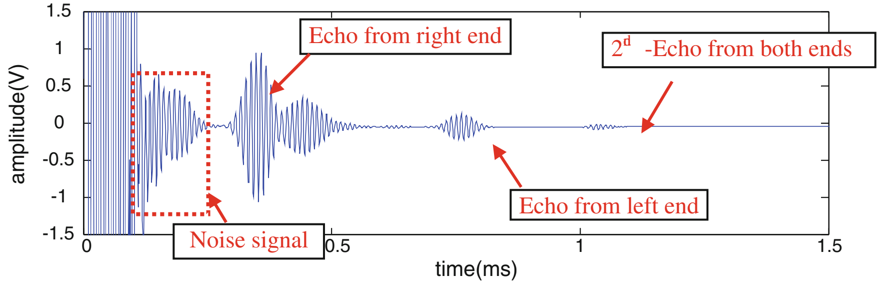


Fig. 4 The reflected signal waveform received by the PZT sensor

2.3 The MsS Installed for Working in the Pulse-Echo Mode

The installation location of an MsS in a 2.02 m wire rope is shown in Fig. 5. Figure 6 depicts the received signal waveform when the MsS was working at 100 kHz in the pulse-echo mode. Although the received signal was amplified by 60 dB, the signal reflected from the left end of the wire rope still had a very low amplitude (<0.1 V). The signal reflected from the left end could not be detected by the MsS. Hence, it is obvious that the PZT had better performance in emitting guided waves by comparing the waveforms as shown in Figs. 4 and 6.

As shown in Fig. 6, the MsS is capable of conducting non-touching inspection to the wire rope. However, it has very poor performance in emitting the desired guided

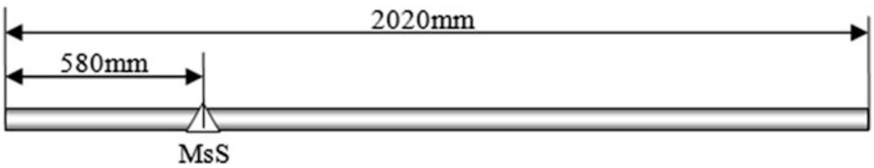


Fig. 5 The installation location of the MsS in the rope

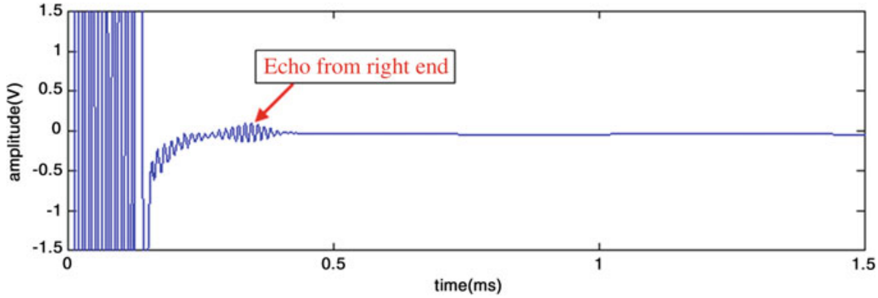


Fig. 6 The reflected signal waveform received by the MsS

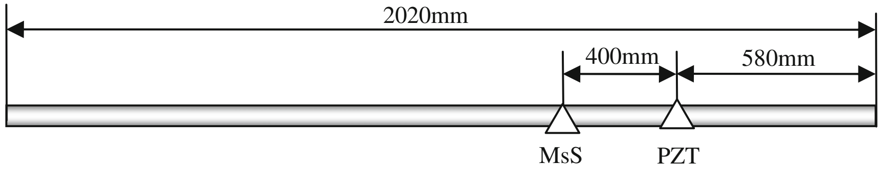


Fig. 7 The installation locations of the PZT and MsS in the rope

waves. Based on the result of previous experiments, when the MsS was working at around 100 kHz, its detection depth was less than 1 mm due to the skin effect of the electromagnetic field. That is, the MsS is more preferable to work as a receiver to receive the guided waves reflected by different types of defects.

2.4 The PZT Works as a Transmitter and MsS Works as a Receiver

In another experiment, the PZT sensor worked as a transmitter/emitter of guided wave and the MsS worked as a receiver of the reflected guided wave. The installation locations of the PZT and MsS are shown in Fig. 7. The gain for the receiver signal was set at 40 dB, and the peak amplitude of the "direct transmission wave (DTW)" was about 1 volt. This peak amplitude is in the same magnitude as that showed in Fig. 2. The "echo from right end" and the "echo from left end" (propagated about 2.48 m) were detected by the MsS. Although the amplitude of the "echo from right end" was smaller than that showed in Fig. 4, it could still be clearly identified. Because the PZT and the MsS was working as a pulse-catch mode, the oscillation signals (noise signal) deduced by the sensor itself was minimized, so that each wave packet in Fig. 8 could be distinguished and tagged with different reflections caused by different defects or conditions of the inspected rope.

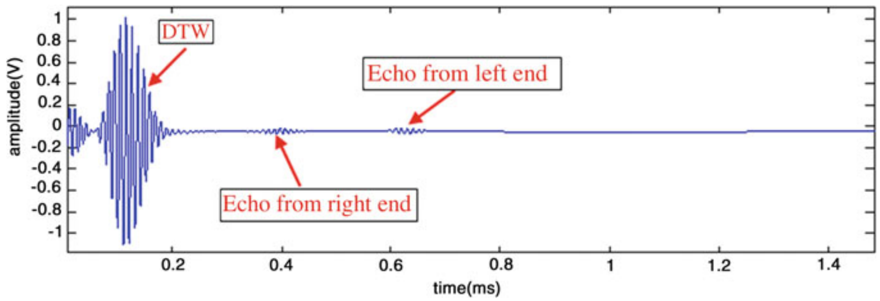


Fig. 8 The reflected signal waveform received by MsS when the PZT was working as the transmitter

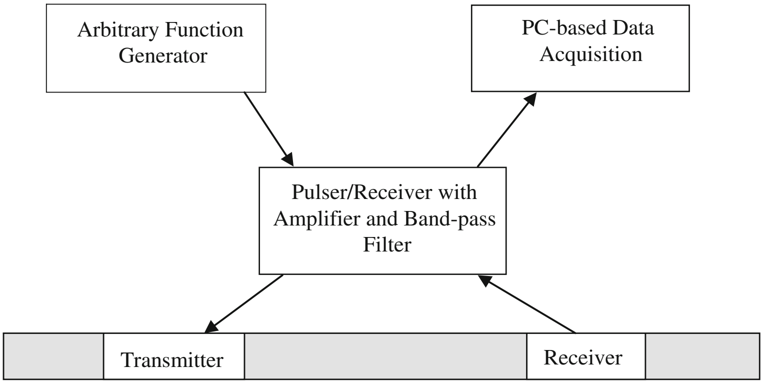


Fig. 9 The experimental set-ups for steel ropes/cables defect inspection

3 Experimental Set-Up and the Results on Broken Wire Detection

The experimental setup for the tested steel wire rope/cable is shown in Fig. 9. Experimental set-up for broken wire detection consists of arbitrary function generator, pulser/receiver with amplifier and band-pass filter, two types of transducers and data acquisition based on PC From the abovementioned experiment, two types of sensors, the MsS and the PZT were used for determining the number of broken wires. Again, the PZT was the transmitter and the MsS was the receiver. The whole transduction system worked in a pulse-catch mode.

3.1 The Determination of Number of Broken Wires in a Steel Wire Rope

The installation locations of PZT and MsS were shown in Fig. 10. The emitted L (0, 1) mode guided wave propagated in both sides of wire rope. The propagation paths of guided wave in the rope are illustrated in Fig. 10. The direct transmission wave from the PZT to MsS, marked as “DTW”, was firstly received by the MsS. The wave packet of “DTW” was overlapped with the initial pulse wave due to the MsS receiver was close to the PZT transmitter. The echo wave from right end of the rope, which is marked as “Echo from right end”, was received by the MsS after the propagating path reached 1.36 m. The echo wave from left end of the rope is marked as “Echo from left end”.

Figure 11a shows the waveform of a signal received from a healthy hoist wire rope. The waveform can be easily identified because there is no overlapping signal or trailing signals occurred as the MsS was the receiver. Figure 11b shows the received signal waveform from a defective hoist wire rope.

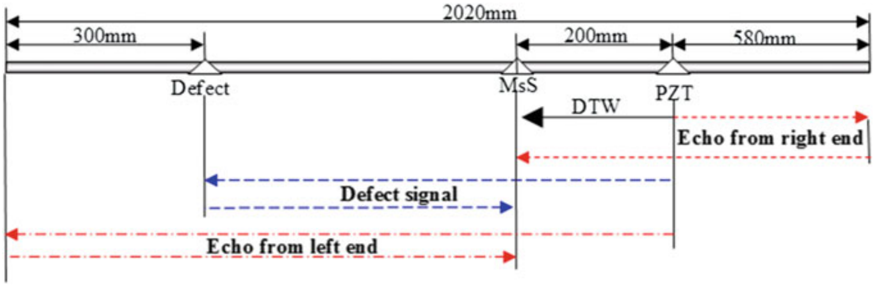


Fig. 10 Locations of PZTW and MsS onto the wire rope and propagation paths of guided wave

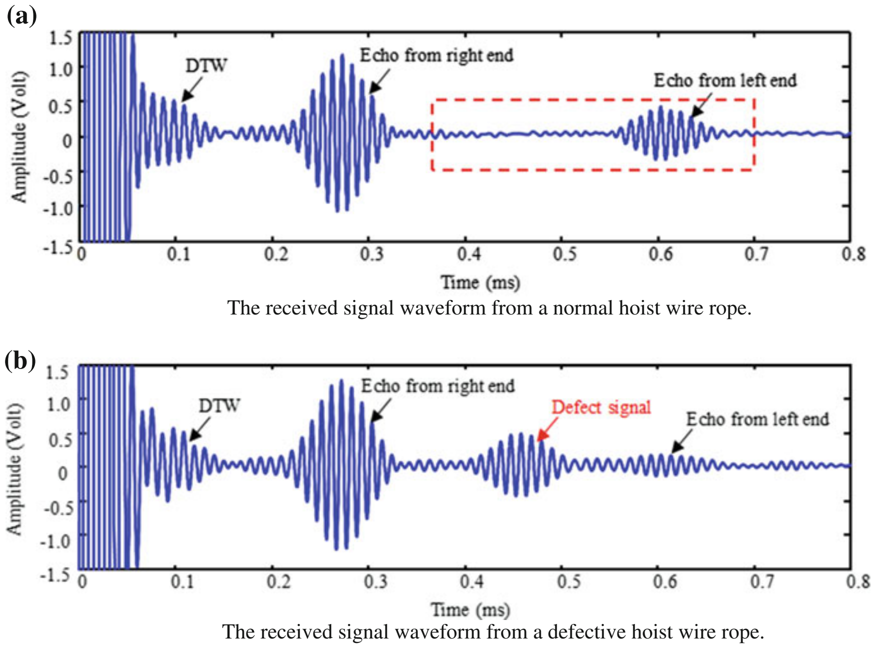


Fig. 11 The typical received signal waveforms in the tested wire ropes. **a** The received signal waveform from a normal hoist wire rope. **b** The received signal waveform from a defective hoist wire rope

The defect of broken wires as shown in Fig. 12 is apart from the left end of the rope for about 300 mm. The amplitude of wave packet "Echo from left end" reduced because a part of the guided wave energy was reflected by the defect before it propagated to the left end of rope. Reflected wave signals were recorded when the number of broken wires increased. The reflected signal waveforms are shown in Fig. 13. It is obvious that no signal was reflected at the marked position of defect in a healthy rope. When four wires were cut off in the defect location, an obvious

Fig. 12 The broken wire defects in the hoist wire rope

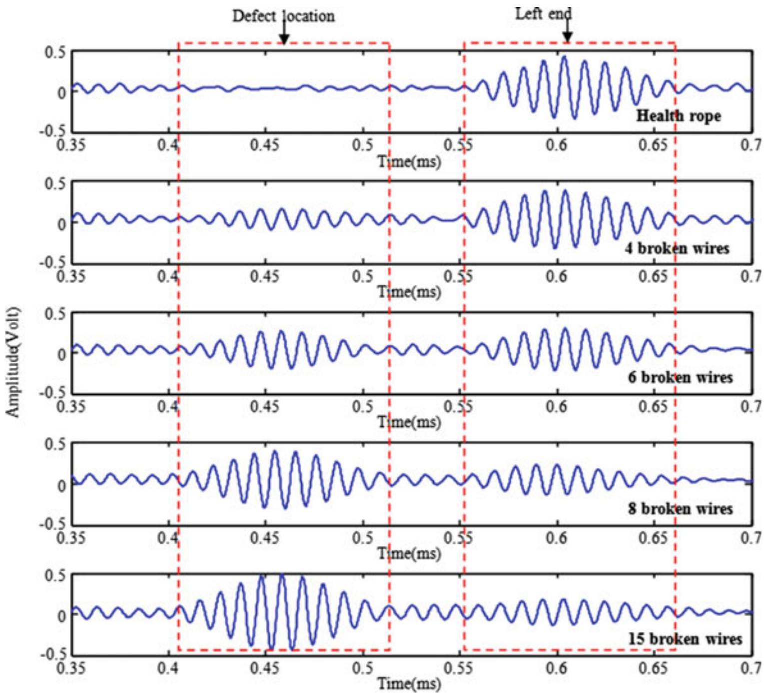


Fig. 13 The waveforms of reflected signal obtained from a healthy rope and several defective ropes with different number of broken wires

reflected wave packet was observed in Fig. 13. That mean, if a defect in the rope has more than four broken wires, which is around 2 % of the total number of wires used to form the rope, the MsS can be detected form analysing the reflected wave signal from such broken wires.

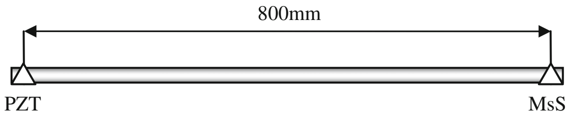


Fig. 14 The installation locations of the PZT and MsS in the rope

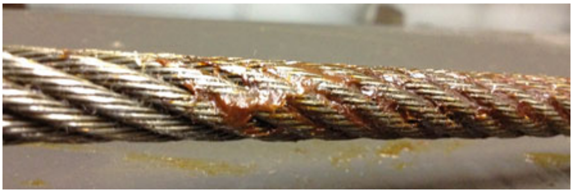


Fig. 15 The lubricating grease coated on the surface of the tested wire rope

3.2 The Inspection of Steel Wire Rope that Was Covered by Lubricating Grease

Because of improper maintenance, the elevator ropes are inevitable become dirty and makes the lubrication grease become dirty too. A proper inspection may not be possible unless the dirt or excess lubricant has been removed. Form our experiments, we found that the dirt or dirty grease will increase the attenuation of the guided wave, hence, reduce the propagating distance of the guided wave. In this study, lubricating grease was applied to the inspected rope to observe the effect on the reflected guided wave. The installation locations of PZT and MsS are shown in Fig. 14. The distance of two transducers was 800 mm apart and the pulse-catch mode was used. The surface of the wire rope was coated with lubricating grease as shown in Fig. 15.

Figure 16 depicts the received signals waveforms from the wire rope with no grease (blue color curve) and the wire rope with lubricating grease (red color curve). The attenuation of the reflected signal waveforms received from a non-coated rope as compared to the rope covered by lubricating grease was about 23 %. Hence, the range of inspection distance will be decreased due to the attenuation of the reflected signal energy. Nonetheless, the reflected signal caused by the cut end can still be clearly observed even the rope was covered by grease.

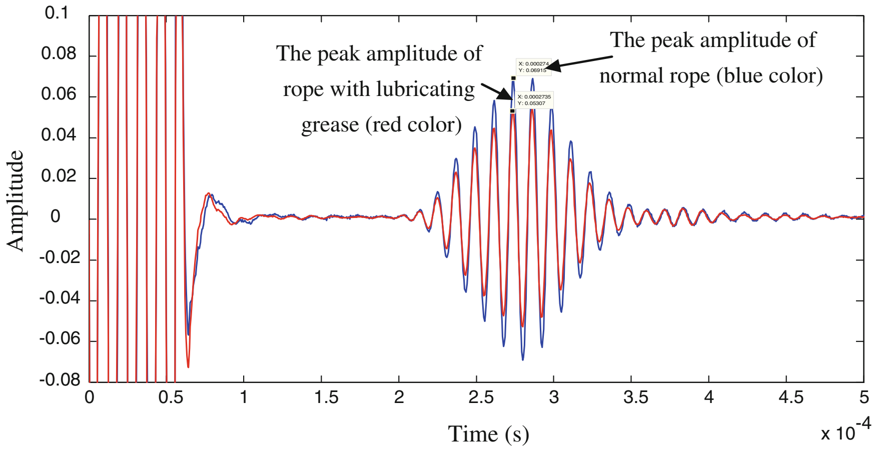


Fig. 16 The comparison on the received signal waveform from rope with/without lubricating grease

4 Conclusion

The results presented here demonstrated the effectiveness of the proposed guided wave technique for inspecting complicated structures, like elevator ropes formed by many twisted wires. The sensors made from PZT and MsS were used to emit and receive guided waves for inspecting the rope defects. The experimental results prove that the PZT sensor is more suitable for working as a transmitter/emitter, whilst, the MsS is better working as a guided wave receiver. Wire rope specimens with different number of broken wires and ropes covered by lubricating grease were tested. The findings were than used to compare with that collected from health ropes and non-greased rope. The results proved that the technique is able to detect the locations of broken wires and then determine the number of broken wires effectively. Basically the technique can detect ropes that have at least four broken wires, which is around 2 % of all wires for forming the rope. Moreover, the range of inspection distance will be decreased when applied to ropes covered by grease due to the attenuation of the reflected signal energy. Nonetheless, the reflected signal caused by the cut end can still be clearly observed even the rope was covered by grease. To increase elevator safety and reliability, it is necessary for the related industries to seriously consider the use of this new inspecting technique for steel wire ropes/cables that are hoisting heavy objects. In future, to ease the process of mounting sensors on ropes, the laser-based guide wave inspection system will be studied as proposed in published research results [5–7]. Such system can truly provide a non-contact type of guided wave emission and measurement method and an easy process in installation.

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