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Corrosion Mapping in Buried Section of Monopoles Using Magnetostrictive Transducer Arrays

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1 Abstract

Tubular steel monopoles are widely used for electrical transmission and distribution lines and lighting fixtures. The cross-sectional shape of the pole can be circular or polygonal. The poles are buried in the ground with the underground section being up to 6 m (20 feet) long. Moisture penetration, road salt, or dog urine can cause corrosion, which can lead to structural failures, mostly in the area of the highest pipe stress close to the point of soil entry or in the first inches below ground. Among possible inspection techniques, ultrasonic guided wave testing has the advantage of being able to inspect the buried and aboveground sections of the pole from a single probe installed at a suitable location, typically 0.6 – 0.9 m (2-3 ft) above ground. This paper presents an approach utilizing guided wave magnetostrictive transducer arrays suitable for inspection of both round and octagonal shaped monopoles. Data is acquired using full matrix capture (FMC), and the acquired waveforms are analyzed using the total focusing method (TFM) to map the condition of the pole. The SH0 guided wave mode was used at frequencies of 30 – 180 kHz. Case studies of corrosion mapping in round and octagonal shaped poles will be discussed.

Keywords: Buried poles, Guided waves, Magnetostrictive Transducer array, Corrosion mapping, Structural health monitoring.

2 Introduction

Guided wave inspection of poles embedded into the ground shares many of the challenges associated with guided wave testing of buried pipelines. These challenges include increased wave attenuation due to interaction with surrounding media, the presence of unknown geometric features, and uncertainty in the morphology and distribution of corrosion anomalies. Soil contact, moisture, and coatings can introduce additional damping mechanisms that reduce inspection range and complicate signal interpretation. In many installations, poles may also be embedded in concrete foundations rather than directly in soil, which further alters boundary conditions and can introduce additional attenuation and mode conversion effects. The mechanical coupling between the

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pole wall and the surrounding medium can significantly influence guided wave propagation characteristics, particularly in the ground-line region where corrosion is most likely to occur.

Buried poles are particularly susceptible to generalized corrosion near the soil interface, where exposure to moisture, oxygen, and aggressive soil chemistry can create highly corrosive conditions. Unlike isolated pits or holes, this type of degradation results in gradual wall-thickness loss over extended axial/circumferential areas, producing relatively weak reflections that can be difficult to distinguish from background structural reflections or noise. As a result, inspection methods must provide sufficient sensitivity to detect these anomalies.

Among the various guided wave modes available for inspection of cylindrical structures, the fundamental shear horizontal mode (SH0) is particularly attractive because its non-dispersive nature allows it to propagate without significant waveform distortion over relatively long distances. In addition, SH0 motion is primarily in-plane shear, which means that it has less sensitivity to external loading from surrounding soil or concrete than longitudinal modes. These characteristics make SH0 well suited for detecting corrosion defects in buried or partially embedded structures.

2 Magnetostrictive Transducers

Magnetostrictive transduction has been widely utilized in NDE applications, specifically for generation and reception of guided waves for long-range inspection of components such as pipes, vessels, and small tubes. Magnetostrictive transducers (MsTs) that use the direct and reversed Wiedemann effect [1,2] have been available for several years. MSTs utilize the magnetostrictive effect in ferromagnetic materials to generate and receive ultrasonic guided waves through the interaction of a dynamic magnetic field produced by a coil and a static bias magnetic field produced by permanent magnets. Figure 1a shows a conceptual design of a reversed-Wiedemann-effect MsT probe. The probe supports broadband operation without requiring coil readjustment or probe modification. The same probe can therefore operate over a wide frequency range of 30–250 kHz. This capability enables the use of an automated frequency sweep, allowing multiple inspection frequencies to be evaluated during a single measurement. Each probe segment has two FeCo strips that are fired independently to provide direction control. The entire sensor assembly is encapsulated into a flexible urethane coating to protect it from the environment.

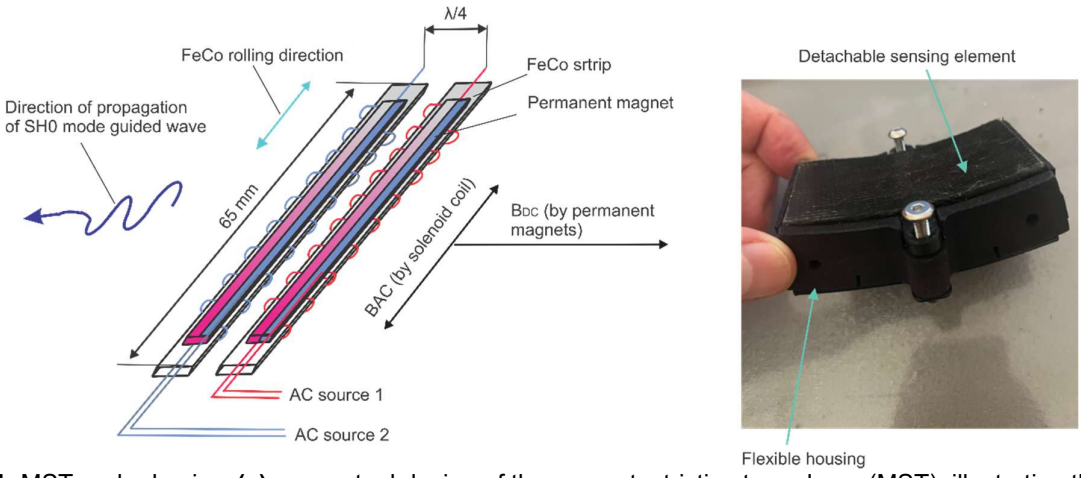


Fig. 1. MST probe basics: **(a)** conceptual design of the magnetostrictive transducer (MST), illustrating the excitation coil, magnetostrictive strip, and bias magnet; **(b)** design of a flexible MST sensing segment used in the circumferential probe array for inspection of poles with varying diameters.

Recent developments in MsT technology have enabled the implementation of probe arrays, in which multiple transducer segments are distributed around the pole circumference. To ensure reliable acoustic coupling between the sensing element and the pole surface, each segment is mounted within a flexible housing incorporating an internal inflatable bladder, as shown in Figure 1b. When pressurized, the bladder expands and pushes the sensing element radially outward, forcing it into contact with the pole wall. This mechanism allows the sensor to maintain consistent contact pressure and alignment even when the probe is installed on poles with different diameters. The articulated segment design allows individual sensing modules to be effectively coupled on both curved cylindrical poles and flat-sided polygonal poles. Adjustable spacing between segments further enhances adaptability, ensuring consistent circumferential coverage and reliable guided wave excitation. Figure 2a shows probe arrays with different numbers of sensing segments designed for poles with outer diameters ranging from 89 mm to 170 mm. Figure 2b shows an example of the 4-segment MsT array probe mounted on an octagonal pole surface. Ultrasonic shear wave couplant is typically used with these probes to provide consistent acoustic coupling.

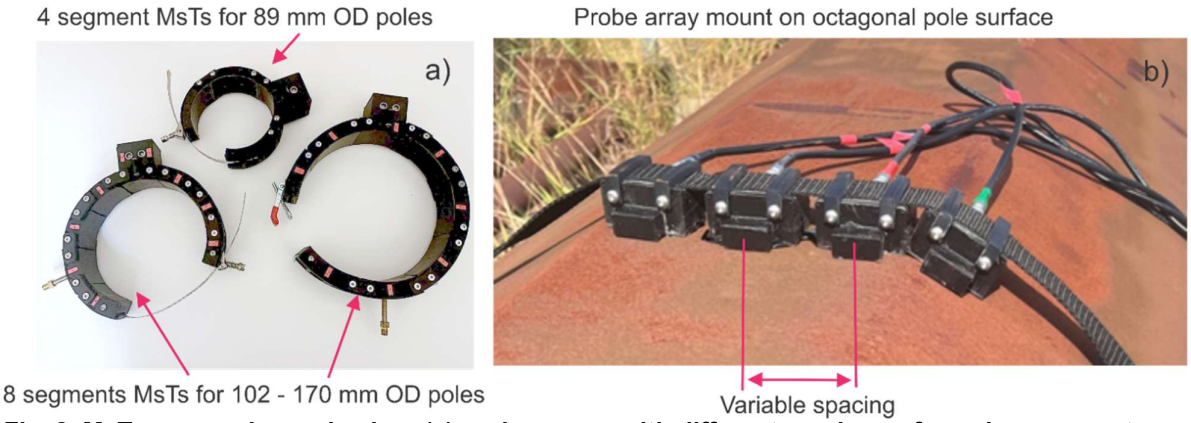


Fig. 2. MsT array probe packaging: (a) probe arrays with different numbers of sensing segments designed for inspection of poles with outer diameters ranging from 89 mm to 170 mm; (b) example of the probe mounted on an octagonal pole surface, demonstrating the ability of the segmented design to conform to non-cylindrical pole geometries.

Signal Processing Using FMC/TFM

The transducer arrays are driven by an instrument allowing full matrix capture (FMC) acquisition; the acquired waveforms are analyzed using the total focusing method (TFM). This new functionality allows 2-dimensional mapping of corrosion in the tested structure, making reporting significantly more informative [3]. TFM approaches provided dramatic improvement in anomaly detection and resolution at the cost of higher computational time and distortion of reflectivity values due to coherent summation of multiple wave packets. Therefore, amplitude normalization and reflector aperture weighting will be required to obtain physically meaningful reflectivity values. Examples of this type of normalization for corrosion mapping in large cylindrical structures were presented in [4]. Figure 3 shows results of a multifrequency scan of a multi-sided pole using a 4-element array MsT probe.

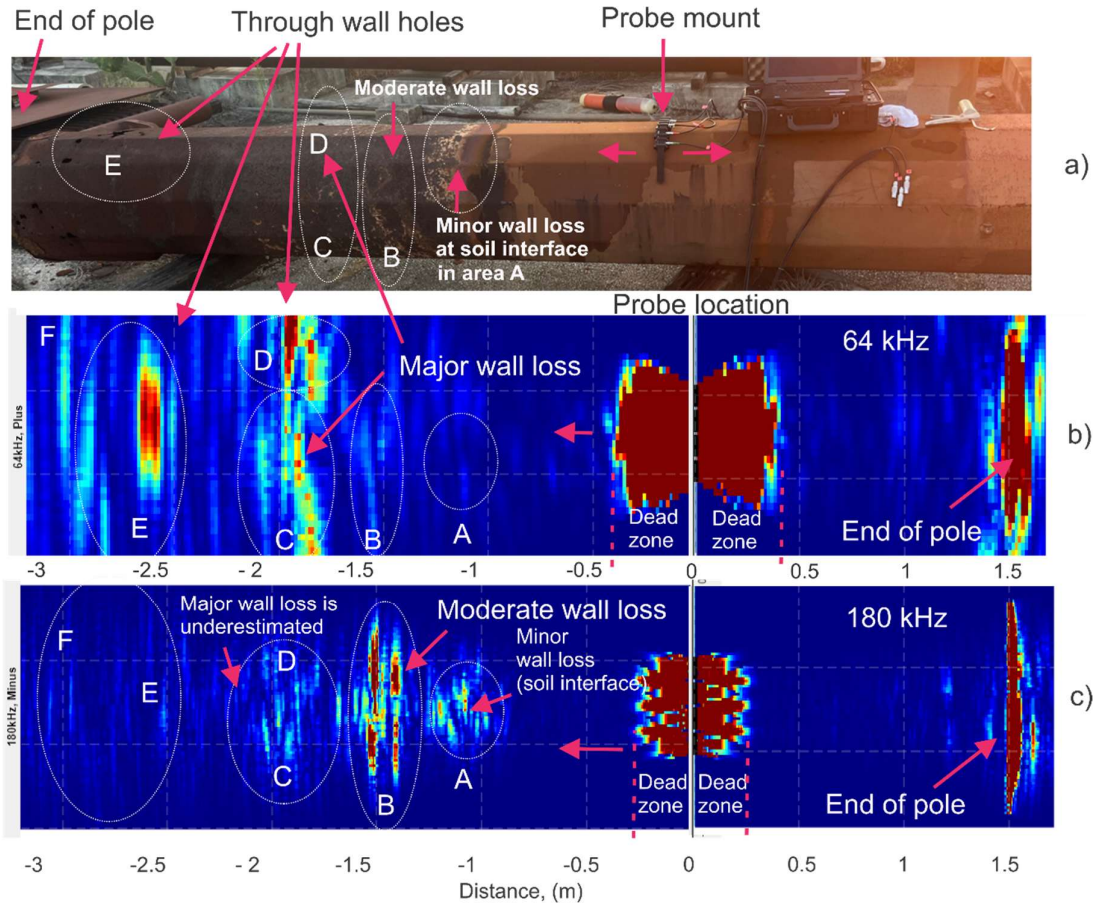


Fig. 3. TFM imaging of a buried monopole using multiple inspection frequencies: (a) photograph of the pole showing locations of corrosion damage and probe position; (b) TFM image obtained at 64 kHz, highlighting major wall loss and through-wall defects; (c) TFM image obtained at 180 kHz, showing improved sensitivity to moderate and minor wall-loss regions near the soil interface.

This particular pole provides a representative example of progressive wall loss, where the wall thickness gradually decreases from near-normal conditions at the soil interface to near-complete loss toward the end of the pole. The results indicate that different inspection frequencies provide complementary sensitivity to different stages of corrosion damage. Minor and moderate wall loss in areas A and B are more clearly captured using higher-frequency guided waves (180 kHz), which provide improved sensitivity to relatively small thickness variations. In contrast, major wall loss regions located in areas C and D are more effectively detected using lower-frequency guided waves (64 kHz) due to their greater penetration capability and lower attenuation.

When 64 kHz guided waves propagate toward the far end of the pole (to the left in Figure 3b), they encounter a major wall loss region at approximately −1.8 m, followed by a series of through-wall holes beginning near −2.5 m. These large anomalies produce strong reflections; however, they also significantly dissipate the propagating wave energy. As a result, the reflection from the end of the pole exhibits relatively low amplitude because much

of the incident wave energy has already been scattered and attenuated by the severe defects.

A similar effect is observed in the 180 kHz data. In this case, moderate wall loss located near −1.3 m reduces the energy available to interrogate defects located farther along the pole. Consequently, the signal amplitudes returned by the major wall loss regions located beyond approximately −1.5 m are reduced. This behavior illustrates how earlier corrosion features along the propagation path can attenuate guided waves and influence the detectability of subsequent defects.

These observations highlight the importance of multi-frequency guided wave inspection, where lower frequencies provide improved sensitivity to severe defects and longer inspection ranges, while higher frequencies enable the detection of smaller or more gradual wall-loss features near the ground-line region.

Case Study 1: Lighting Pole Embedded in Soil

An example of corrosion detection near the soil interface in a 102 mm OD buried lighting pole using a 4-segment array MsT probe is shown in Figure 4(a) Some visible discoloration near the soil line suggests corrosion activity. Guided wave data acquired at 180 kHz are shown in two formats: (b), Total Focusing Method (TFM) and (c), corresponding B-scan. The TFM reconstruction provides improved spatial resolution and clearer visualization of the corrosion region compared with the B-scan representation. Despite the relatively high inspection frequency, the reflection from the end of the pole remains clearly visible.

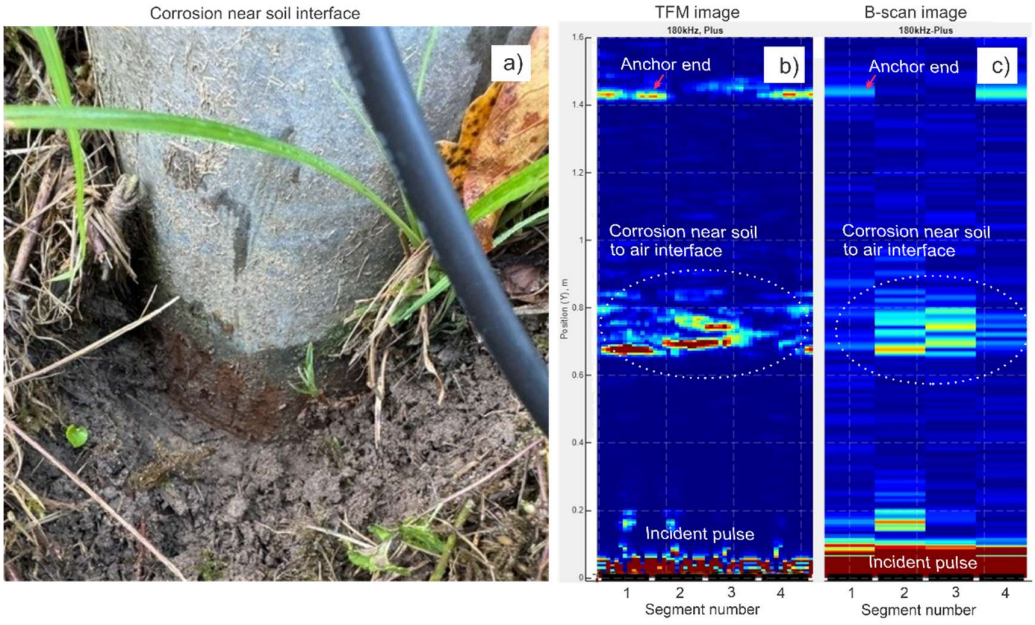


Figure 4. Detection of corrosion near the soil interface in a buried monopole. (a) Soil interface of a buried 102 mm OD lighting pole, where discoloration near the soil line suggests corrosion activity. Guided wave data acquired at 180 kHz are shown in two formats: (b) Total Focusing Method (TFM) image and (c) corresponding B-scan image.

Case Study 2: Lighting Pole Embedded in Concrete

In some cases, portions of the pole may be embedded in a concrete foundation, which significantly alters the boundary conditions for guided wave propagation [5]. The interface between steel and concrete introduces a mechanical impedance mismatch, which can cause partial reflection, and mode conversion of guided waves at the interface. As a result, the concrete transition region may produce reflection indications in the guided wave signal, which must be distinguished from reflections originating from corrosion defects or other structural features. Additionally, energy leakage into the surrounding concrete can increase attenuation and reduce inspection range. Understanding these effects is therefore important when interpreting guided wave data acquired near concrete interfaces in pole inspection applications.

Figure 5a illustrates an example of guided wave inspection of a pole embedded in a concrete foundation. The probe was mounted near the ground line, and measurements were performed at two excitation frequencies. At 180 kHz, a pronounced reflection is observed at the location corresponding to the steel–concrete interface, indicating a strong interaction between the guided wave and the concrete boundary, see Figure 5(b). Several additional reflections are visible above this region and are attributed to geometric features near the pole bottom.

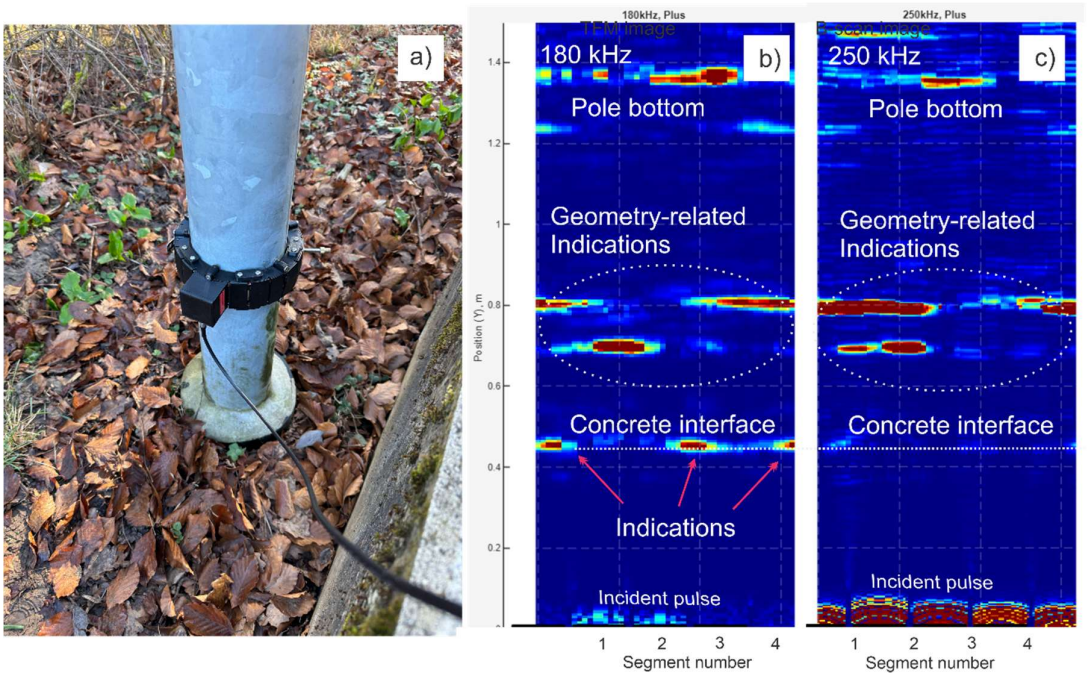


Figure 5. Example of guided wave inspection of a steel pole embedded in concrete. (a) MST probe mounted on the pole near the ground line. (b) Data acquired at 180 kHz, showing a strong reflection associated with the steel–concrete interface. (c) Guided wave data acquired at 250 kHz.

Figure 5c presents the data acquired at 250 kHz. The reduced amplitude of the concrete-interface indication, compared to 180 kHz, is attributed to increased leakage of guided-wave energy into the surrounding concrete at higher frequencies. Nevertheless, a distinct reflection from the pole end is observed, indicating that sufficient energy remains for reliable detection of major geometric features even under higher attenuation conditions. While higher frequencies offer improved axial resolution due to shorter wavelengths, their effectiveness for detecting generalized corrosion may be limited. In practice, the response from the concrete interface is best assessed using a frequency sweep, with the optimal inspection frequency selected based on the peak amplitude of the interface reflection.

Conclusion

This work demonstrates the feasibility of guided wave inspection of buried monopoles using flexible circumferential magnetostrictive transducer (MST) probe arrays. The MsT probe design allows rapid installation around poles with varying diameters and geometries, including both cylindrical and polygonal cross-sections. The segmented housing and bladder-assisted coupling mechanism enable quick mounting of the transducer without complex alignment procedures, which is particularly advantageous for field inspections.

The MST probe supports broadband operation over a frequency range of approximately 30–250 kHz. The associated electronics (MSSRV5M unit) and software enable automated frequency sweeping, allowing multiple inspection frequencies to be evaluated during a single measurement and providing rapid imaging of the pole condition.

Overall, the MST probe array provides a practical and efficient solution for rapid screening of buried monopoles, enabling detection of corrosion near the ground line while minimizing the need for surface preparation, probe repositioning, and mechanical scanning.

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