

Detection and Location of Coating Delamination and Anomalies on Buried Pipelines with Electromagnetic Reflectometry

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ABSTRACT

This paper covers a case study performed on 10-inch diameter steel pipelines in an urban environment to detect and locate coating anomalies (such as holidays and disbondment) with a novel technique and methodology. A survey tool and theoretical framework have been introduced, and the practical feasibility of wielding reflectometry of electromagnetic waves in buried steel pipelines to assess coating condition was trialed. The authors were able to model different reflectometry signatures obtained from different coating conditions. Differential Reflectometry Mapping (DRM) methods were found to be able to detect coating defects, including coating delaminations; and to accurately locate those defects at a distance of 1500 ft. This presents a clear progress for current state of the art capabilities in terms of remote coating assessment in buried pipelines while detecting disbondment conditions. DRM permits a unique improvement regarding integrity management for transmission and distribution of liquid assets.

Key words: Corrosion, Pipeline, Detection, Buried, Coating, Holiday, Delamination, Insulation, Reflectometry

INTRODUCTION

Corrosion control of buried assets usually involves a double shield: a coating system as a physical insulation barrier, and a cathodic protection system as an additional ad hoc defense. Detection of a corrosion spot at the coating defect stage is the only way to identify the threat before significant metal loss occurs. Furthermore, detection of defects in the coatings of such assets is especially important, since large defects, if left unrepaired, will not only leave the asset locally prone to corrosion, but also drain and weaken the cathodic protection effectiveness for the entire structure. Therefore, identification and characterization of coating anomalies is critical for the integrity of buried assets.

The case of coating delamination and CUI

A type of coating defect known as delamination or disbondment of the coating has received renewed interest. A coating delamination consists in an area of non-adherence between the coating and the metal, associated with a local porosity that allows the intake of water and electrolytes beneath the coating. It generates an especially dangerous risk for the pipeline asset: not only does it make the metal beneath it prone to a localized attack, but it also shields it from the cathodic protection system. This unique threat, also known as CUI (Corrosion Under Insulation), has attracted special attention due to the lack of technologies able to detect this condition.

Challenges of the urban environment

Corrosion management of buried pipelines for electrical utilities in cities face additional challenges. High voltage cables are required to be buried in urban environments. Since the end of the 19th century, the historical solution is to encase triphasic cables in 10-inch steel pipes. This system is called high pressure fluid-filled pipeline (HPFF, with HPGF being the gas variant).

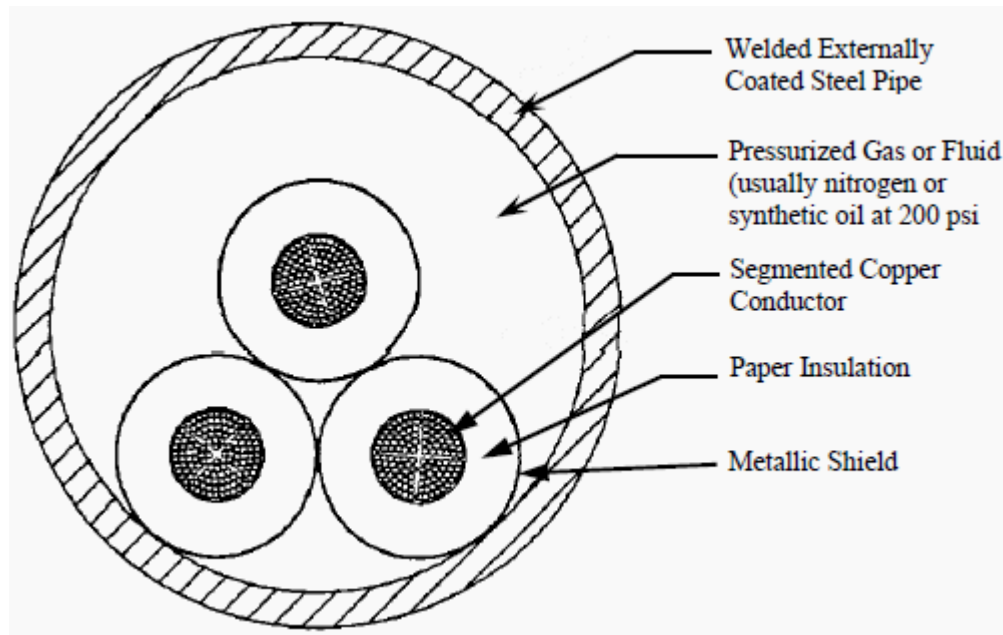


Figure 1: HPFF pipe cross-section¹

These pipes are not surveyable with ILI because of the cables present inside the pipes, and the presence of concrete, roads, pavement, as well as the depth at which those pipes can be buried make over-the-line methods such as DCVG (Direct Current Voltage Gradient) unreliable for coating assessment². This typically leaves electrical utilities with no good tool to survey their feeder lines for early corrosion detection.

An apparatus and a method have been designed to wield reflectometry of electromagnetic waves in buried pipelines systems³. A signal is sent along the line, and any coating defect induces a reflection on such a signal. This technology allows targeting of repair excavations efficiently where they are truly needed and hence to generate important savings.

The architecture of the technology itself correlates signal reflection with corrosion susceptibility: If there is a localized corrosion vulnerability at some point in the pipeline, then there is at this location some electrochemical contact between the steel of the pipe and electrolytes, and therefore the signal will experience some leakage into the ground, which then translates into a signal reflection which is read and analysed. Furthermore, operation of electromagnetic reflectometry at relatively high frequencies offers a sensitivity for the detection of coating delamination significantly superior to over-the-line techniques.

THEORETICAL ASPECTS

The transmission line theory covers the modelling of long, parallel conductors. The configuration of these parallel conductors induces a coupling of the electromagnetic waves travelling in these conductors, and this coupling and the properties that ensue is the object of study of transmission line theory. Historically, it has been used extensively for phone and power lines.

The central definition and property of a transmission line is its characteristic impedance Z_c . In a transmission line comprising two parallel conductors characterized by an inter-conductor lineic capacitance C , a lineic inductance L , a lineic resistance R , and a lineic conductance G , as represented on figure 2, we define its characteristic impedance as follows⁴:

$$Z_c = \sqrt{\frac{R + jL\omega}{G + jC\omega}}$$

Equation 1

With ω being the frequency.

It has been found that when other pipelines are present in the right of way (as often is the case for electrical utilities in cities) it is best to use two pipelines transmission as a waveguide for the signal. Using a one pipeline/soil transmission line presents practical difficulties⁵. The framework that has been developed in this study is different than classical fault detection applications of reflectometry since a fault in that case is not modelled by a shunt between both conductors but a shunt between a conductor and the ground surrounding both conductors figure 2. We called this framework the three media transmission line.

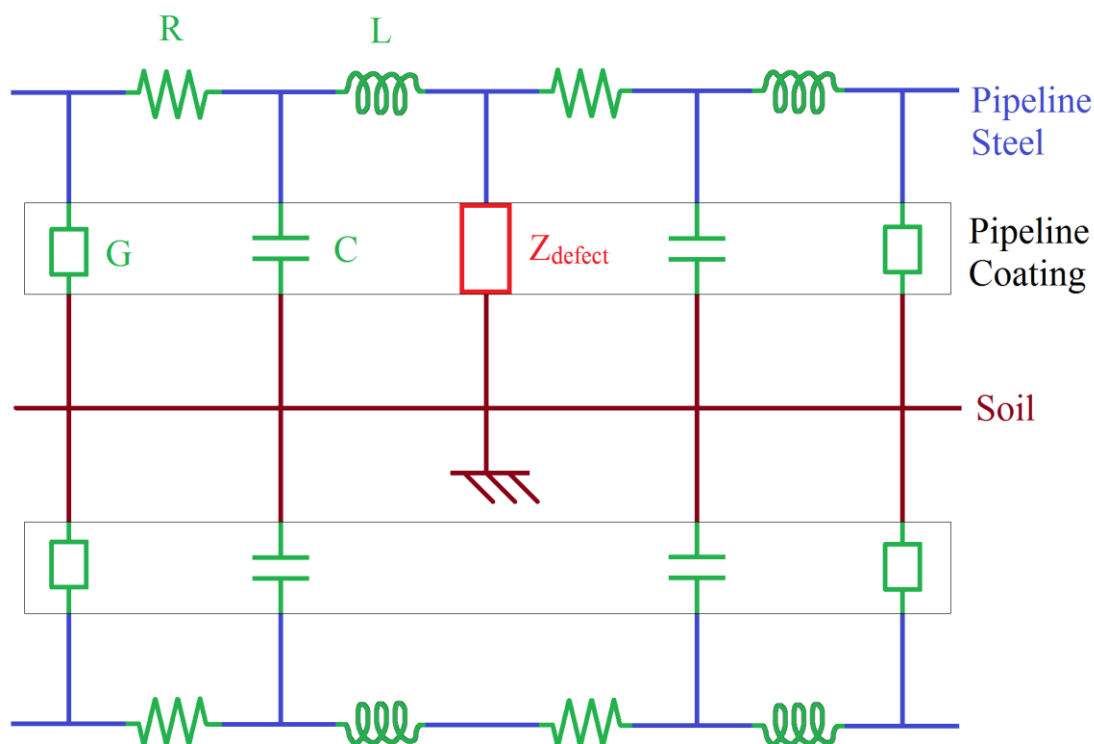


Figure 2: Three media transmission line model

EXPERIMENTAL PROCEDURE

Electric utilities companies have access points, known as manholes, regularly distributed over their buried pipeline network. It was decided to use those manholes to connect to the pipeline network and perform the field testing of this reflectometry technology.

The procedure for setting up the hardware for a reflectometry profile measurement was to cut open 3-inch by 3-inch square patches in the coating of both pipelines, prepare the steel surfaces for good electrical contact and to connect both the signal generator and the probe onto those surfaces figure 3. A square signal was then sent. It is important to note that due to this standard configuration the signal travels both ways (in the example represented, northbound and southbound).

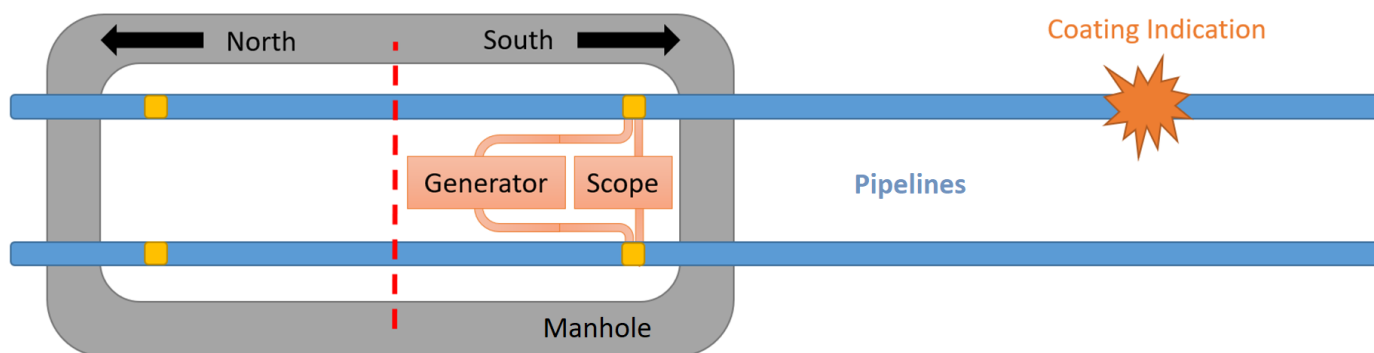


Figure 3: Typical manhole field setup

RESULTS AND DISCUSSION

In accordance with the theoretical framework, in the case of a pipeline section with intact coating, the voltage measured was found to be relatively flat after the initial impedance transition reflection (due to the impedance mismatch between the cables and the pipeline transmission line). Conversely, a coating locally damaged will induce a signal reflection at that location that will be seen from the measurement point with a time lag. For ease of interpretation, the x axis can be converted from a time scale to a distance scale by dividing it by twice the signal propagation velocity (since the signal has to travel forth and back). We call the resulting plot the reflectometry profile of a surveyed pipeline section. On figure 4 the reflectometry profiles of two equivalent manholes of a section coated with coal tar are plotted together, one with intact coating and one with damaged coating close to the measurement manhole.

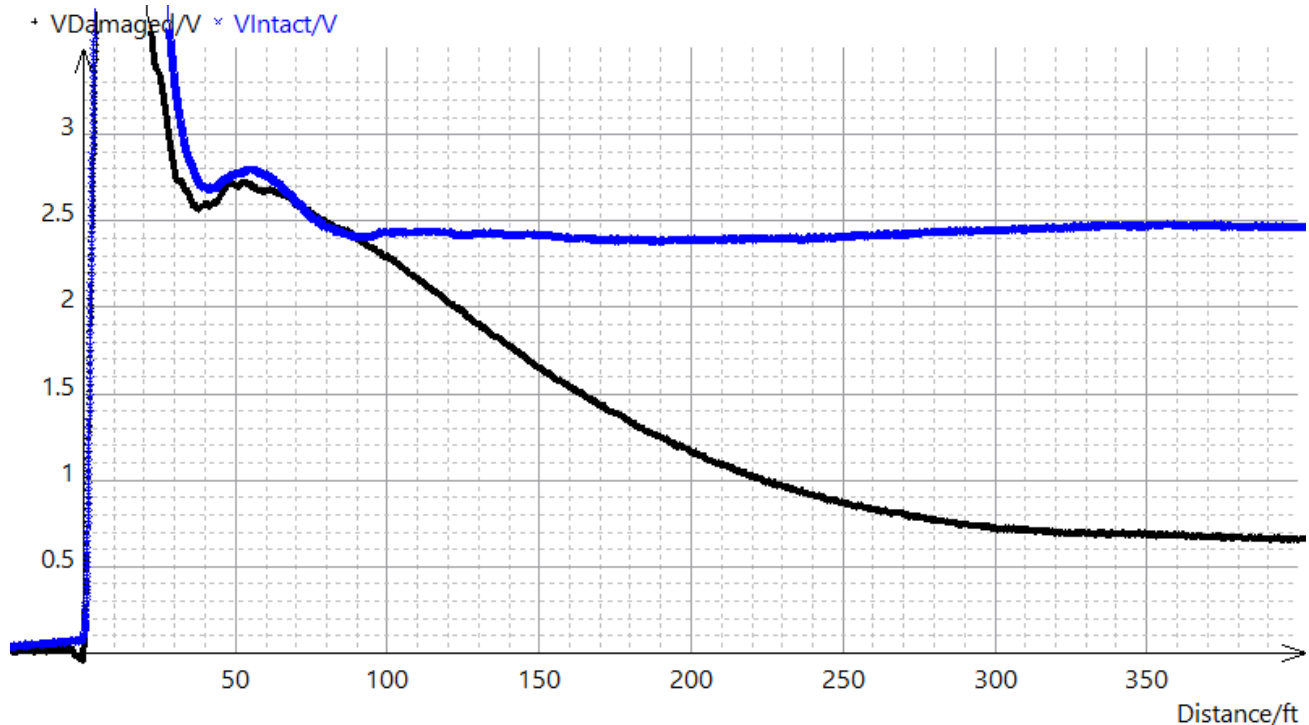


Figure 4: Reflectometry profiles comparison of an intact and a damaged section

The “bump” seen approximately between 35 and 85 feet is not due to local changes in the coating but to the pipelines moving closer together near the manhole (see figure 5).

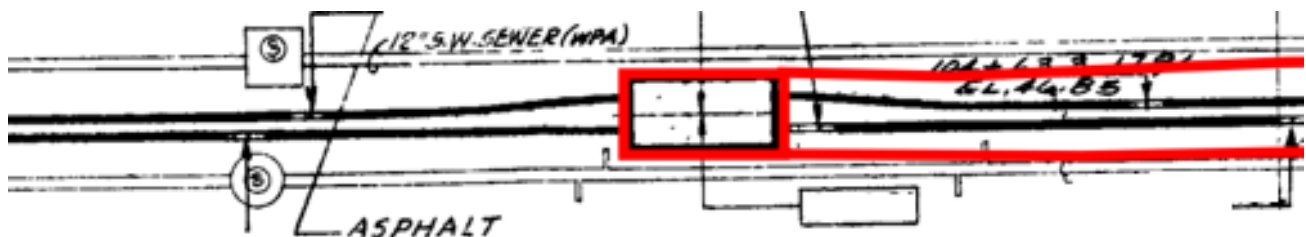


Figure 5: Subsurface drawing of a typical urban manhole and feeder system