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Fault Detection in Conductive Pipelines by Time Domain Reflectometry

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Abstract - An experimental investigation is performed to carry out the feasibility of using an electrical method for the detection of defects in conductive pipelines. The pipeline, with an auxiliary conductor acting as signal return, is treated as a transmission line, and the time domain reflectometry (TDR) technique is used to reveal the presence of holes or defects. The introduction of the auxiliary conductor reduces considerably the influence of the pipeline installation features on the propagation of electrical signals along the pipeline (i.e., presence of ground, impact of the weather conditions on the ground electrical parameters, etc.). Suitable statistical processing of the TDR measured data allows the pipeline fault identification. The proposed method is appealing since it may represent a continuous and economic diagnostic method for testing the pipeline integrity.

Key-Words: Pipelines, TDR, transmission lines.

1. Introduction

One of the main problems in the fluid distribution networks (gas, water, etc.) consists in the individuation of the state of the pipes in order to avoid losses which could cause economic damage and, sometimes, in case of flammable fluids, dangerous situations. Often, these networks are buried in urban environment so that direct inspections result unsuitable for a periodical evaluation of the maintenance state. Moreover, possible defects on the internal surface can not be revealed by the visible inspection. Therefore, due to its low efficiency and high costs, the technique based on the visible inspection is not adequate.

In the past, various monitoring techniques based on the generation of elastic waves have been developed and used. According to these techniques, the possible defect which represents a discontinuity point, produces reflected and transmitted waves, and therefore a distorsion in the elastic waves propagation [1-4]. Even if these techniques are still now considered, they present some drawbacks related to the limited explorable length, and to the strong sensitivity of the propagation alteration on the possible presence of pipes in the neighbouring which may produce echoes [5], or can contribute to a reduction of the reflected or transmitted signal, increasing the complexity of algorithms for the defect identification. Moreover, they often require a complex installation of the set-up for the generation of suitable elastic waves.

Other methods based on non-destructive tests by using eddy currents, require the accessibility of the structure under test [6-7], and, therefore, are not of great utility in dealing with buried pipes.

A system based on the propagation of the elastic waves, known as lamb-waves or SHW (shear-horizontal wave) [8-10], is realized by a transducer that converts, by magnetostriction [11] or by piezoelectricity [12], the electrical signals produced by a suitable source in elastic waves at a frequency in the range between tens of kHz and some MHz, depending on the propagation of the used ultrasound wave and on the pipe type to be inspected. The signal is obtained by a transducer positioned at the end point of the pipe which measures the transmitted wave, and by the same (or another) transducer used to generate the wave which measures the reflected wave. Acquisition, visualization and data elaboration systems permit to evaluate the presence of faults and defects.

This work deals with the experimental investigation of the propagation of electrical signals instead of traditional acoustic waves along metallic pipelines to carry out the feasibility of using an electrical method for the detection of defects in conductive pipelines [13].

The main idea comes out from the analogy between the Navier and Maxwell equations which describe the propagation of acoustic and electromagnetic waves respectively. Time domain reflectometry (TDR) is used to localize possible defects or changes of the pipeline thickness due to corrosion.

2. Fault detection by means of TDR

The TDR is widely used in the cable faults detection and are based on the excitation of the line by suitable reference signals and on the analysis of the line input voltage: when defects are present, the change in the cable impedance related to the discontinuity produces some reflections which can be easily observed in the input voltage. Moreover, since both the transmitted and the reflected waves travel at the same speed, it is possible to derive the exact distance of the fault from the observation point, and in some cases it is also possible to have a guidance about the type of the defect.

In order to apply to a conductive pipeline the TDR for fault detection, it is convenient the use of an auxiliary conductor for the returning path signal because of repeatability of measured data offered by such a solution, e.g. with respect to a ground return. In this case, the metallic pipeline together with this auxiliary conductor can be regarded as a transmission line. This pipeline-auxiliary conductor configuration in the following will be denoted as DUT (device under test). An experimental activity has been developed on several iron pipelines of length 2 m, external radius 3 cm and thickness 3 mm, adopting an auxiliary conductor of section 10 mm^2 which has been fixed to the pipeline by plastic ties. The experimental results achieved adopting auxiliary conductor of different cross-sections, have shown a low variability among different configurations. The TDR measurements have been realized by the Vector Network Analizer (VNA) P8753E, equipped with the time-domain option. The connection between the DUT and the VNA has been realized by a N-cable and an adaptor N-BNC. The central pin on the BNC connector has been fixed to the pipeline by a metallic tape, while the auxiliary conductor has been joined to the adaptor ground. The other end of the DUT is left in the open configuration. The adopted procedure consists in the preliminary TDR measurement on an intact pipeline in order to characterize the propagation of the reference configuration. Then, the TDR measurement has been repeated on pipelines exhibiting one of the two following defect types:

A. hole with increasing circular cross section at a distance d = 1.2 m from the pipeline left end, as shown in Fig. 1 where the three situations of

(1) non-perforating 1 mm-deep,

(2) perforating 3 mm-wide and

(3) perforating 5 mm-wide holes are depicted.

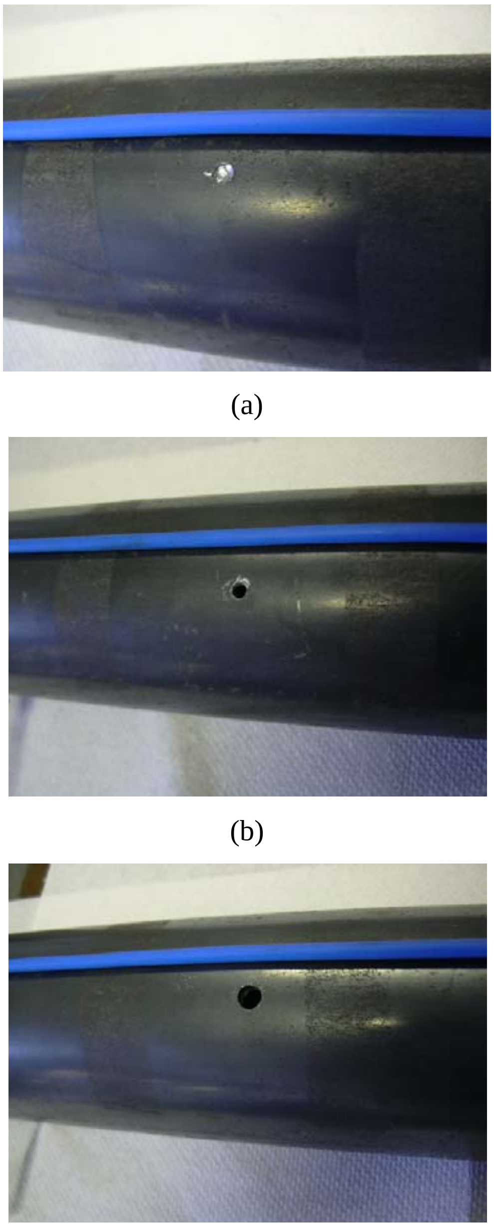
The hole has been realized close to the return wire; in order to assess the sensitivity of signal transmission and reflection to its position, other mutual positions (hole-return wire) have been also considered and will be presented in the following.

B. Linear cut with rectangular cross section in transversal plane of increasing dimensions at a distance d = 1 m from the pipeline left end, as shown in Fig. 2. Dimensions of the cut are: 1.5 mm the width in all the three cases, and

(1) length = 10 mm, depth = 1 mm,

(2) length = 20 mm, 2 mm and

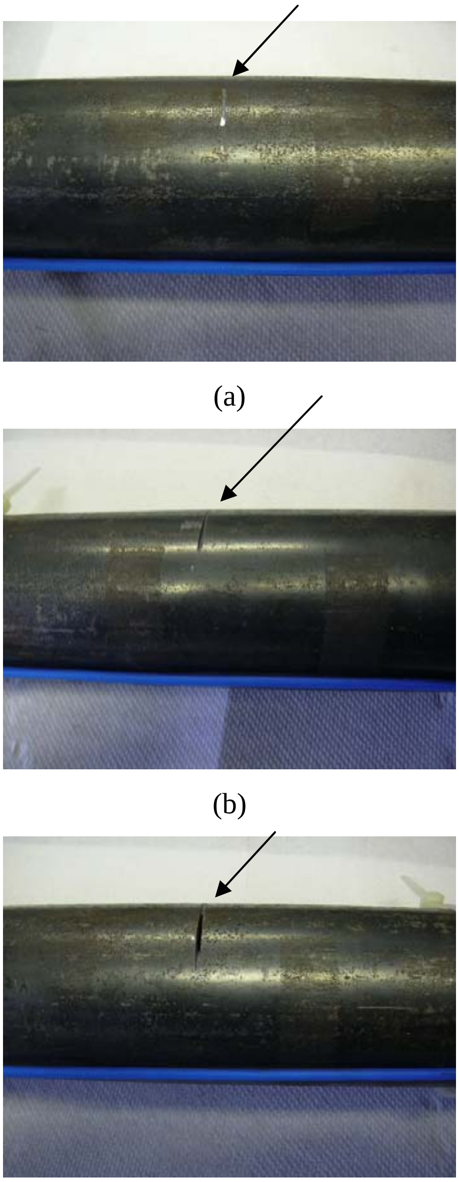
(3) length = 20 mm, depth = perforating (3 mm).


(a)

(b)

(c)

Figure 1 – Hole defect of circular cross section with increasing size.



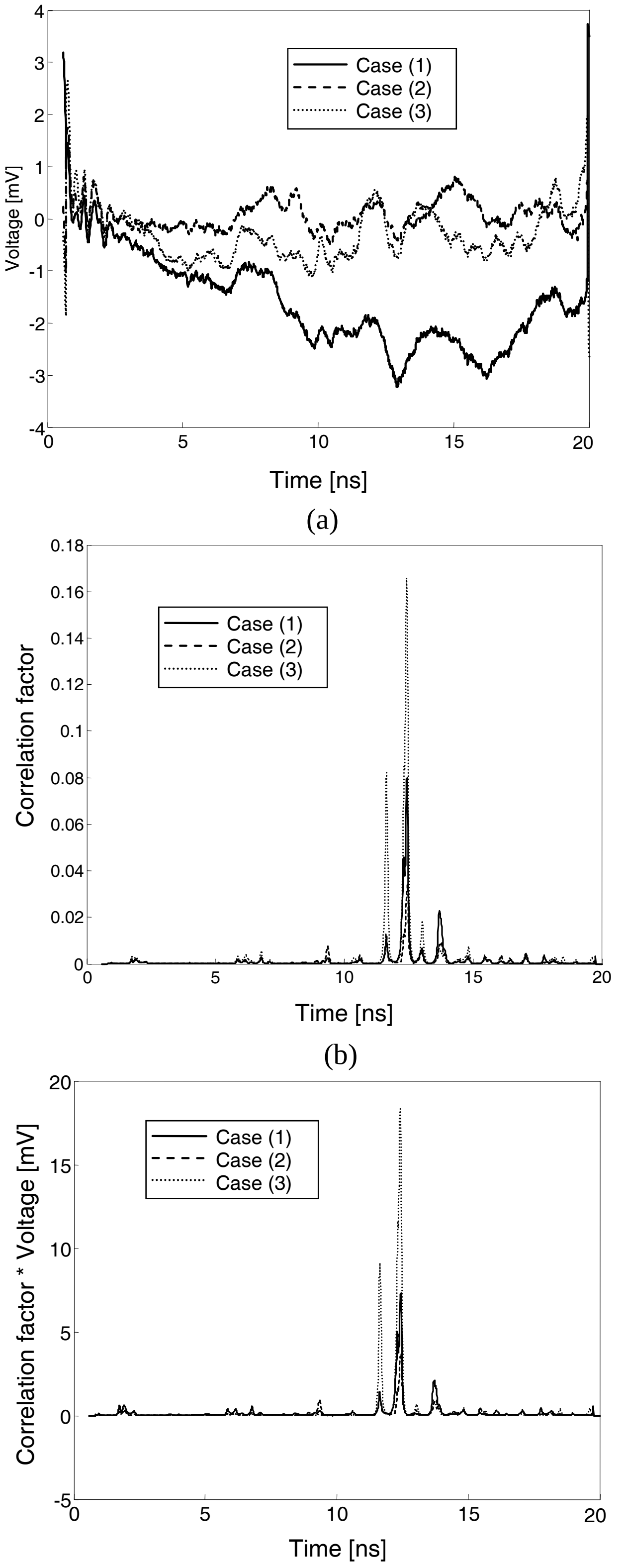
(a)

(b)

(c)

Figure 2 – Hole defect of a transversal, rectangular cross section with increasing size.

The analysis of the measured data has put in evidence that a simple difference of the signals obtained in absence and in presence of the defects is unsuitable for any diagnostic purpose. Thus, two other possible post-processing algorithms have been explored: a cross-correlation between the two series (in time) of measured data and the product of the cross-correlation by the difference between the signal measured in absence and that got in presence of the defect. In this way, as reported in the following figures, it is clearly evident the presence of a discontinuity and also its position along the pipe may be predicted with an accuracy acceptable for maintenance intervention.

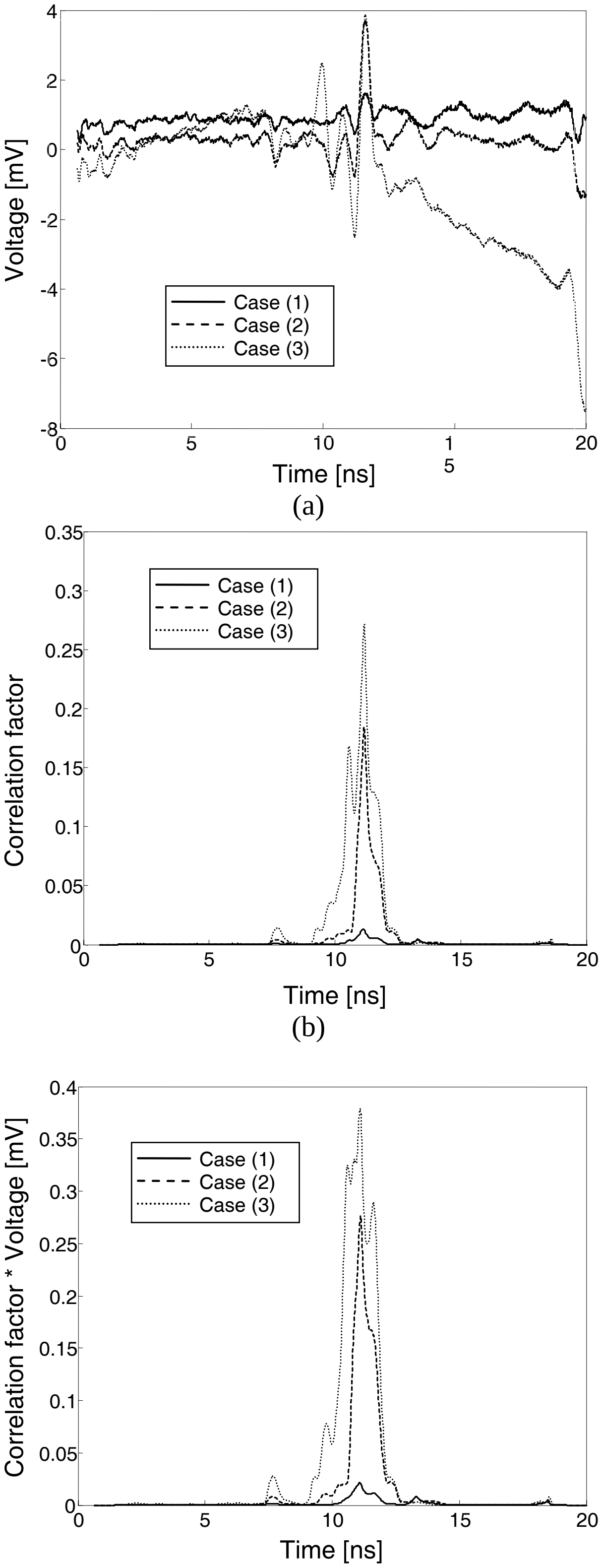


(a)

(b)

(c)

Figure 3 – Signal processing results of the TDR measurements for the circular hole: (a) difference between reference data and data in presence of defect, (b) cross-correlation, (c) product difference by cross-correlation.

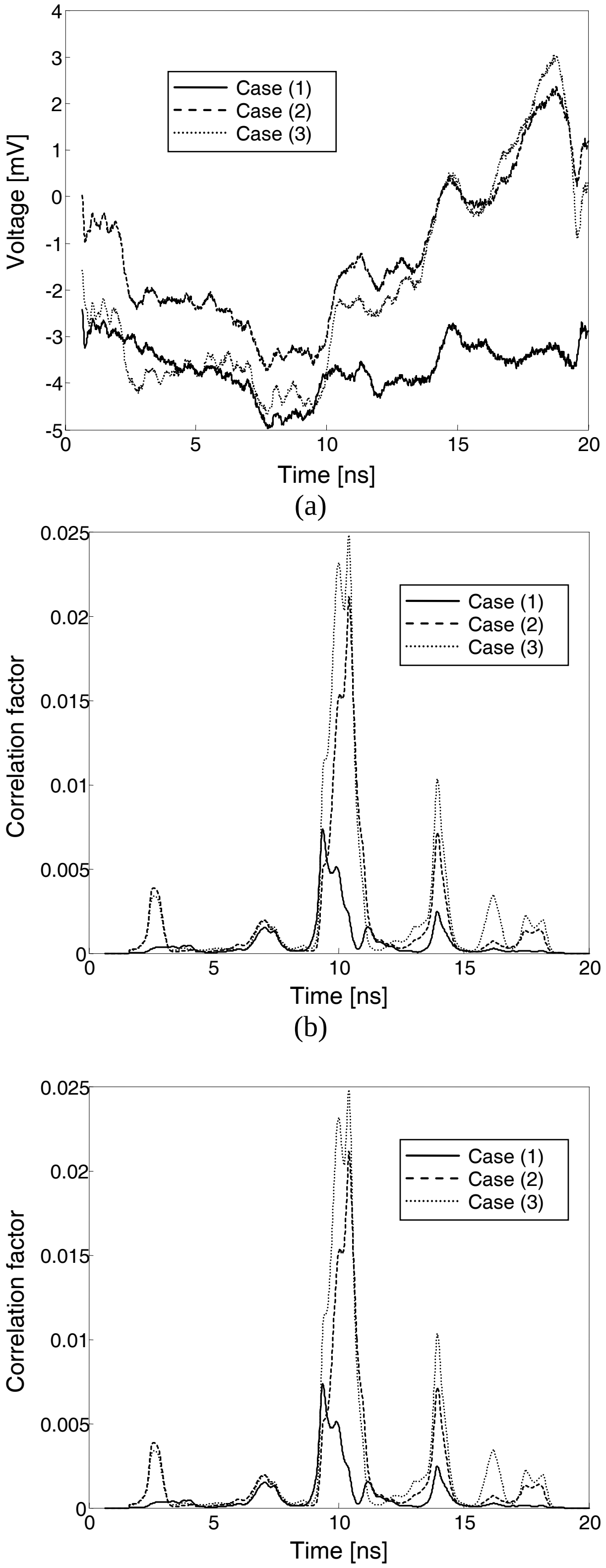


(a)

(b)

(c)

Figure 4 – Signal processing results of the TDR measurements for the transversal rectangular hole: (a) difference between reference data and data in presence of defect, (b) cross-correlation, (c) product difference by cross-correlation.



(a)

(b)

(c)

Figure 5 – Signal processing results of the TDR measurements for the longitudinal rectangular hole: (a) difference between reference data and data in presence of defect, (b) cross-correlation, (c) product difference by cross-correlation.

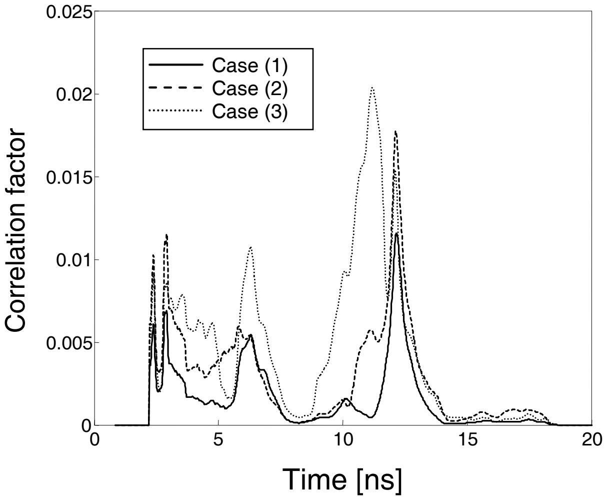


Figure 6 – Signal processing results of the TDR measurements for the circular hole located at 90° from the return wire.

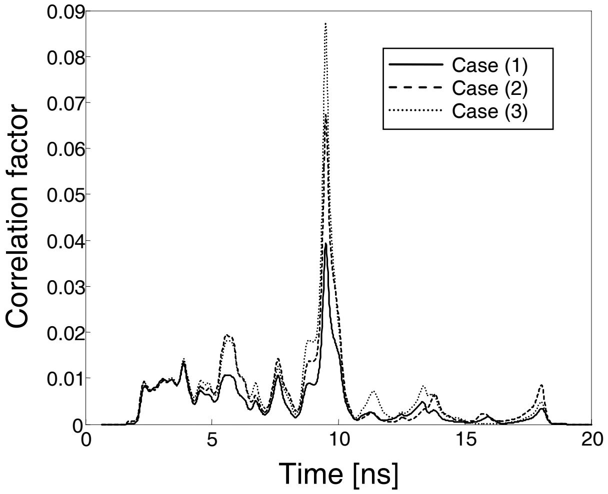


Figure 7 – Signal processing results of the TDR measurements for the transversal rectangular hole located at 180° from the return wire.

3. Conclusions

An alternative technique for the diagnostic of buried pipes based on the time domain reflectometry has been presented. Experimental data in various defect configurations have shown that the technique is reliable in putting in evidence not only the presence of the discontinuity but also its position along the length of the pipe. Further investigations will concern the analysis of multiple defects and the possibility of discrimination of the importance of the defect for maintenance planning.

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