Detecting Flaws in Buried Pipes Under Rough Surface Using The Natural Frequency Technique

Fadi Deek* and Magda El-Shenawee
Department of Electrical Engineering
University of Arkansas, Fayetteville, AR 72701, USA
E-mail: fdeek@uark.edu

Introduction

It is an industrial requirement that material carrying pipes be frequently maintained. Several noninvasive techniques were developed such as trained dogs that sniff or listen to leaks, a laser controlled camera inside a pipe or X-ray tubes to photograph the pipes [1]. Yet, ground penetrating radars, GPRs, have shown the best efficiency. Several techniques were used to process the GPR profiles in order to extract features that characterize the media such as back propagating neural networks [2] that identify hyperbolic effects of buried pipes.

In recent works [3], [4], the idea using elliptical antennas with notches as RFID has been explored for detecting cracks in pipes. Complex natural poles unique to the structure were extracted from the scattered field and used as an identification key. Projecting this onto buried pipes, it is expected that a pipe with a crack will have poles that are in excess to a pipe with no cracks [3], [4].

FEKO simulations are used to generate the scattered field. A PEC pipe that is 10cm long with a diameter of 2.5cm and 5 mm thick is used for the proof of concept of the above idea. The pipe, once with a crack and once with no crack, is simulated in free space, hidden behind or immersed in a plywood wall and buried underneath sand. The synthetic data is corrupted with white Gaussian noise up to SNR = 10dB. An algorithm is presented to further process the data and to render it suitable for pole extraction using the matrix pencil method (MPM) [6].

Matrix Pencil Method

A data sequence can be represented as a sum of exponentials and their residues as shown in equations (1-3) [5].

$$X(k) = \sum_{i=1}^{M} R_i z_i^k \ for\ k = 0,1,\ldots N \tag{1}$$

$$where\ z_i = e^{-(\alpha_i + j\omega_i)T_s}\ ;\ e^{-\alpha_i} = \text{damping factors and } \omega_i = \text{frequencies} \tag{2}$$

$$R_i = A_i e^{-j\Phi_i} \tag{3}$$

The poles are the Eigen value solution of $zI = X_1^{+} X_2$ where I is the Identity matrix, the X matrices are the shifted version of the original data matrix (+ denotes the conjugate transpose). It should be noted here that the parameter M in (1) truncates the number of poles. Several values of M are investigated in this work.

978-1-4244-4968-2/10/$25.00 ©2010 IEEE

Electromagnetic Configurations and Results

In the first simulation, a pipe of the aforementioned dimensions with no cracks immersed in free space is excited with a plane wave in the –z-direction. This case is considered as the reference. A pipe with a 6cm arc length crack as shown in Figure 1a is considered. Figure 1b shows a comparison of the magnitude of the scattered far field of both cases at an observation point of 60 cm away from the pipe. A Gaussian filter is applied to the synthetic data to limit the bandwidth [7]. The filtered scattered field is then Fourier transformed into the time domain. The matrix pencil method is applied to the late time window to eliminate the incident wave. The extracted pole pairs with dominant residues are shown in Figure 2a. A value of M = 6 was found to extract the pole pair for the reference pipe and is later used as a starting point when evaluating other pipes. For a pipe with the 6cm arc length crack, for M = 8 the reference 1 GHz pole pair was extracted along with two extra significant poles at 3Ghz and 9.1 GHz. These poles are associated with the crack.

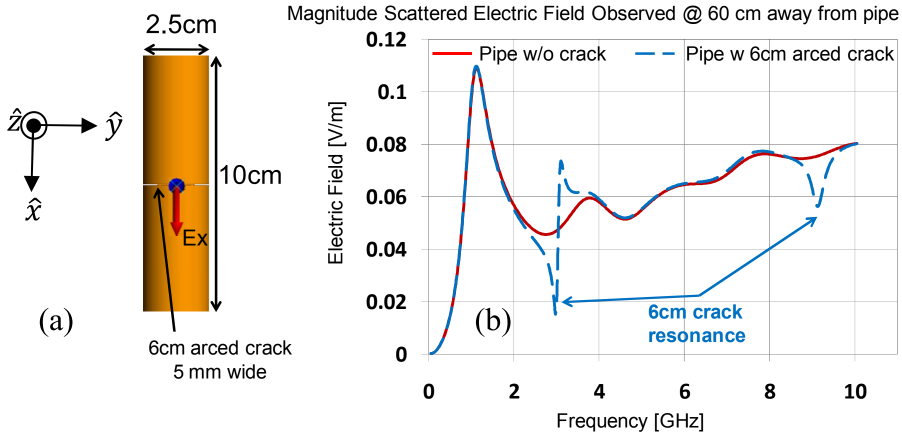

Figure 1 (a) Pipe Dimensions; (b) Magnitude of scattered field @ 60cm away from pipe

The results of Figure 2 show that the crack was detectable even when corrupting the data with noise of SNR = 10dB as shown in Figure 2b. However, at that noise level, the higher frequency pole at 9.1GHz associated with the crack was not extracted.

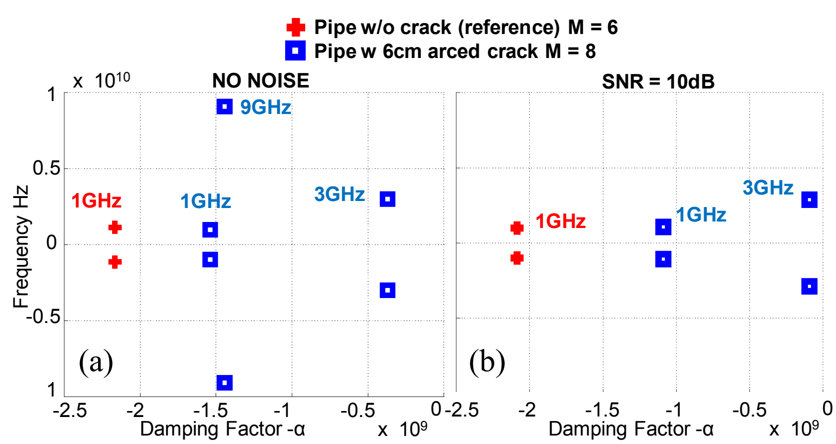

Figure 2 (a) Extracted poles w/o crack; (b) Extracted poles w SNR = 10dB

The second case is a pipe with a 4cm arc length crack. The crack was simulated in two different positions; once on the top of the pipe and once on the bottom of the pipe. The scattered fields are plotted in Figure 3a and are compared with the reference pipe (no crack). It can be seen from Figure 3b that all poles were extracted even when the 4 cm crack was hidden underneath the pipe. The data was corrupted with a SNR = 10dB and the cracks were detectable in both cases (not shown here).

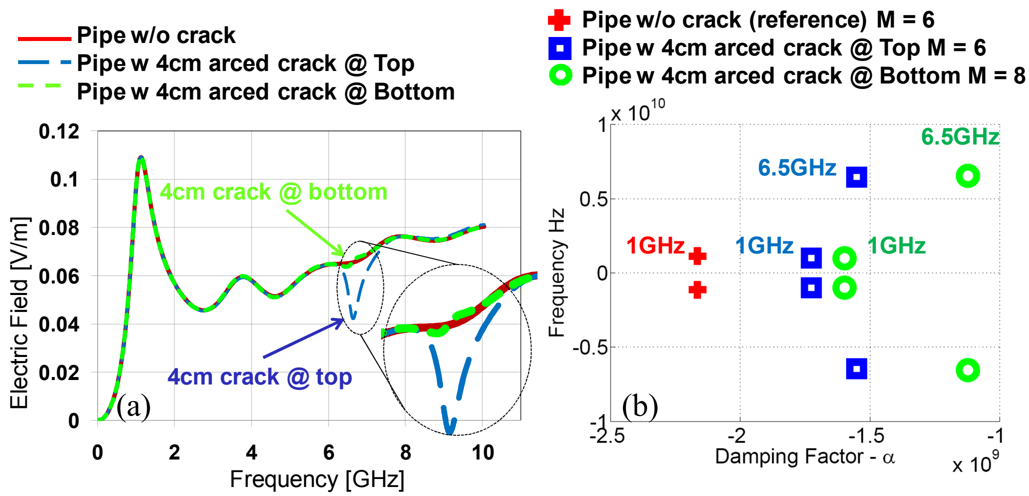

Figure 3 (a) Extracted poles; (b) Scattered Field Magnitude

The algorithm was tested against more challenging cases. The first of which was hiding the pipe behind an infinite 10cm thick plywood wall having $\varepsilon_r = 1.9$ and tanδ= 0.027. The pipe was 5cm away from the wall. Plane waves excited the geometry from the other side of the wall. The observation point was 60cm away from the surface of the wall. The four plots in Figure 4a show the scattered fields of a pipe immersed in free space and those of the hidden pipe. The poles in Figure 4b show that the poles associated with the 6cm arc length crack in the hidden pipe were extracted.

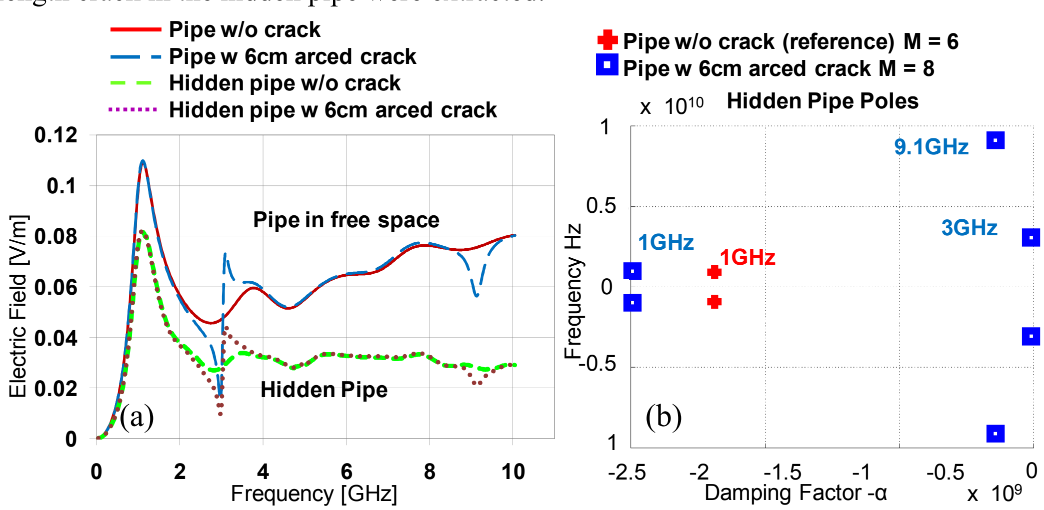

Figure 4 (a) Scattered Field Magnitude; (b) Extracted poles for hidden pipe

Another case was to bury the pipe at 7.5 cm beneath the interface of the half space of sand having ε_r =2.54 and tanδ= 0.005. Due to the change of contrast between the pipe and the surrounding space, the “Buried Pipe” scattered fields in Figure 5a show a left shift in the peaks. This was reflected in the poles plot of Figure 5b which also confirmed that the crack was successfully detected through the 1.8GHz and 5.6GHz poles.

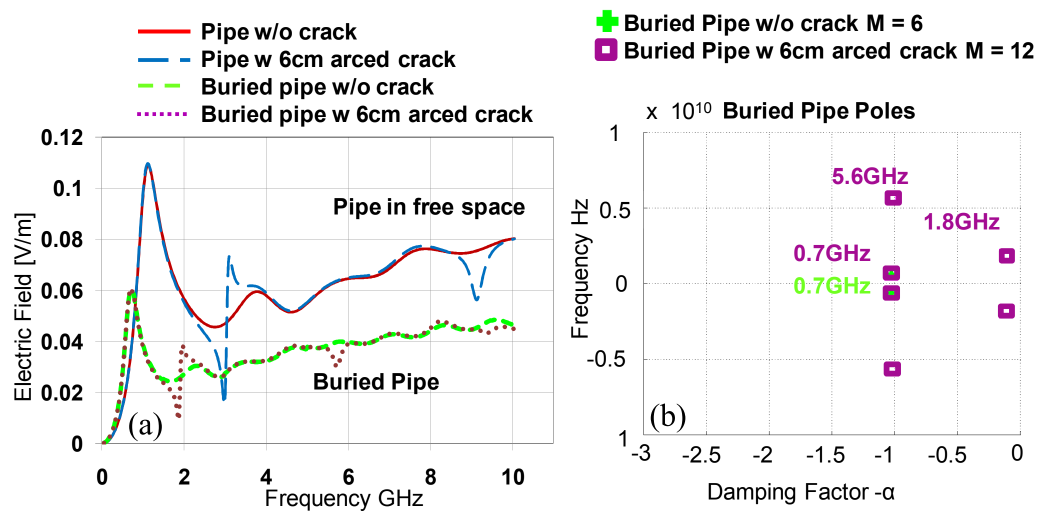

Figure 5 (a) Scattered Field Magnitude; (b) Extracted poles for buried pipe

Conclusion

The matrix pencil method is a MatLab friendly algorithm that generates results in real time. The technique was able to detect cracks in pipes whether they were on top of the pipe or on the bottom up to a SNR = 10dB. Also cracks in hidden and buried pipes were detected using the same technique.

Acknowledgments

This work was funded by Entergy Incorporation. The authors would also like to acknowledge EM Software & Systems for their support in using FEKO.

References

[1] Electric Power Research Institute: http://www.epri.com

[2] W. Al Nuaimy, Y. Huang, M. Nakhkash, M.T.C Fang, V.T Nguyen and A. Eriksen "Automatic Detection of Buried Utilities and Solid Objects with GPR Using Neural Networks and Pattern recognition", *Journal of Applied Geophysics 43, 2000, p157-165*

[3] F. Deek, J. Rutledge, R. Hajihashemi, A Hassan, D. Woten and M. El-Shenawee, "Automated GPR Surface Scanning System for Investigation of Defects in Buried Pipes", *IEEE Int. Symp. On AP-S and USNC/URSI, Charleston, June 2009.*

[4] F. Deek and M. El-Shenawee, "Crack Detection In Buried Pipes Using Complex Resonant Frequencies", *USNC-URSI, Boulder, January 6-9, 2010.*

[5] A. Bliscak, M. Manteghi "Pole Residue Techniques for Chipless RFID Detection", *IEEE Int. Symp. On AP-S and USNC/URSI, Charleston, June 2009.*

[6] Y. Hua and T. K. Sarkar, "Matrix pencil method for estimating parameters of exponentially damped/undamped sinusoids in noise," *IEEE Trans. on Acoustics, Speech and Signal Processing, vol.38, no.5, pp.814-824, May 1990*

[7] R. Adve, T. Kumar, O. Pereira-Filho, S. Rao, "Extrapoloation of Time-Domain Responses from Three-Dimensional Conducting Objects Utilizing the Matrix Pencil Technique", *IEEE Trans.s On Ants. And Prop., Vol. 45, No. 1, January 1997*