Acoustic Detection of a Non-Metallic Object Embedded in a Ground Material

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Abstract: Preliminary results of acoustic detection of non-metallic objects embedded in a ground material model at a shallow depth is investigated. The frequency range of the acoustic wave is optimized to the composition of the ground material model to obtain minimum attenuation of the received signal. The investigation considers both theoretical and experimental aspects of the problem to provide a better understanding of the interaction of the acoustic waves with the ground model and the embedded non-metallic object. One part of the theory is aimed at finding the optimal acoustic signal with maximum ground penetration as a function of frequency, band-width, signal energy, and other wave characteristics. The other part considers ground material characteristics such as grain size and contact areas, density, rigidity and porosity. In the experimental investigation both through-transmission and pulse-echo methods are used. The results lead to relationships between the optimal frequency for maximum amplitude of the received signal, wave velocity, band-width, incident direction, signal energy, attenuation, ground material and the embedded object characteristics.

INTRODUCTION

Currently embedded objects with some quantity of metal in their construction can be detected by such means as pulsed induction-metal-detectors. However non-metallic embedded objects are difficult to detect. The currently known techniques of detection are electromagnetic wave detectors such as ground-penetrating-radar, infrared, X-ray and laser-acoustics, among others. The electromagnetic wave techniques are limited in sensitivity to large sizes of the embedded objects and to the contrast in dielectric properties of ground material. The above methods are also influenced by the electrical conductivity of the ground material. In addition, they are ineffective in very wet environment. In contrast, ultrasonic waves have two major advantages over other current techniques. Firstly, they are sensitive to density, rigidity and stiffness contrasts and therefore they can better distinguish between different materials. Secondly, they can be used to detect small embedded plastic objects in wet and even water saturated ground. However, to our knowledge, currently no ultrasonic techniques for plastic object detection are in field use.

TECHNICAL SUMMARY

The aims of this research are to evaluate and demonstrate the feasibility of ultrasonic detection of plastic embedded objects, including those in the wet material environment, and to develop algorithms to estimate size and depth of the detected embedded object. The technical approach is to develop an ultrasonic technique for the detection of non-metallic embedded objects by theoretical modeling and by experimentation. One part of the investigation is the laboratory test phase, using the following unique capabilities in our laboratory: (1) a computer model for optimizing wave propagation in ground material, with the mapping of received signal intensity and time-of-flight. (2) Ultrasonic transducers for non-contact air-coupled transmission and detection. (3) Digital signal processing capability used to reduce background random grain-noise, and (4) Computer enhanced 3D imaging. Among the factors being considered are ultrasonic pulse shape, pulse duration, amplitude and frequency content. These are being evaluated as a function of ground model material parameters, such as: grain-size distribution, density, humidity, inhomogeneity, temperature, among other parameters.

In the second part the optimal ultrasonic system configuration is used to probe model embedded plastic objects in field type of material. This part includes modeling of acoustic scattering from the embedded plastic objects by simulation (on a Silicon Graphics work station), forward and back-scattering spectral analysis of signals received through ground material, validation by field tests of the theoretical findings of optimal signal (minimum attenuation and optimal resolution) tests of predicted detection criteria, field test estimation of depth, size and shape of the embedded plastic objects. Preliminary results are shown in Figures 1A, and 1B. These figures show...
respectively signal peak-to-peak amplitude, Figure-1A, and signal arrival-time, Figure-1B, of an ultrasonic signal, transmitted through two granular materials layers of uniform grain diameters of 6 mm and 4 mm, with and without an embedded object, the layer thicknesses were respectively 63.5 mm and 52.4 mm.

CONCLUSION

The preliminary results obtained indicate that a non-metallic object embedded at a shallow depth in a granular water saturated ground model can be detected by through transmission of the ultrasonic waves. Pulse-echo technique is essential for certain detection applications when only ground surface is accessible. Low signal-to-noise ratio of pulse-echo technique requires special signal analyses to eliminate grain noise.

FIGURE 1. (A) Peak-to-Peak amplitude, and (B) Signal arrival-time of an ultrasonic pulse of 500 kHz center frequency transmitted through granular materials of uniform grain diameters of 6 mm and 4 mm, with and without an embedded hollow object.

REFERENCES


