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USE OF ULTRASONIC TECHNOLOGY FOR SOIL MOISTURE MEASUREMENT

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ABSTRACT

In an effort to improve existing soil moisture measurement techniques or find new techniques using physics principles, a new technique is presented in this paper using ultrasonic techniques. It has been found that ultrasonic velocity changes as the moisture content changes. Preliminary values of velocities are 676.1 m/sin dry soil and 356.8 m/s in 100 % moist soils. Intermediate values can be calibrated to give exact values for the moisture content in an unknown sample.

INTRODUCTION:

ultrasonic waves have been used extensively for material characterization and for sensing of material parameters[1,2]. Sound waves indeed are capable of providing useful information about the medium through which they travel. ultrasound is an extension of the audible sound and differs only in frequency range and not in principle. The waves produce small amplitude mechanical vibrations which are made to propagate through the sample under test. ultrasonic waves propagate through the material, the change their velocity and are attenuated depending on the material properties and are detecteda. The characteristics of the ultrasonic waves are modified as they travel through the material due to reflection scattering, and absorption. The detected signal can be displayed, processed and interpreted in terms of the properties of the material under investigation based upon its relation to the input wave. We feel that information about soil moisture can be obtained by measuring both the velocity and attenuation of the ultrasonic wave. The attenuation of an ultrasonic wave is associated with absorption and scattering of elastic waves by structural inhomogeneities. Scattering may be the governing attenuation mechanism in this medium. Because our interest is in measuring the moisture content in a variety of soil types, we have looked at the both the velocity difference and the attenuation.

The velocity of sound waves in water as determined in our experimental setup is 1558.6 m/s and in air it is 317.9 m/s measured at room temperature (21°C). It is estimated that the velocity of sound waves in dry soil and 100% moist soils differ by as much as 319.3 m/s and we will be able to interpolate an accurate scale for the determination of soil moisture.

PRINCIPLE OF ULTRASONIC TESTING

Consider an elastic medium as a network of atoms in a crystal lattice connected to each other by elastic forces. Suppose that a plane of the atoms at the surface of the medium is displaced by an external force following a harmonic function. All of these masses will undergo harmonic oscillation in the same phase. The elastic forces are transmitted to the adjacent plane, then to the next adjacent plane, and so on. If the particles were rigidly coupled, the displacement and motion would be transmitted instantaneously. However, the elastic forces introduce a time delay that increases with distance. The above described phenomenon is an elastic wave, which is called an ultrasonic wave if its frequency is higher than 20 kHz. Two modes of propagation are possible in an infinite medium:

(1) longitudinal waves or pressure waves by which particles are displaced along the direction of propagation,

(2) shear waves or transverse waves by which the particles are displaced perpendicular to the direction of propagation.

In longitudinal waves, the sound velocity c_t is determined by the density p, the modulus of the elasticity E, and the Poisson ratio σ in an infinite medium[3,4]:

$$c_t = \sqrt{\frac{E}{\rho}\frac{1-\sigma}{(1+\sigma)(1-2\sigma)}}, \qquad (1)$$

$$c_t = \sqrt{\frac{\nu}{\rho}}, \qquad (2)$$

where v $=\lambda'+2\mu, \lambda'$ and μ are Lamé constants.

Considering plane waves, attenuation A after traveling a distance r with incident amplitude A_0 is;

$$A = A_0 e^{-\alpha r} \qquad (3)$$

The attenuation coefficient a is given by

$$\alpha = \frac{1}{r}\ln\frac{A_0}{A} \qquad (4)$$

For ultrasonic waves in a homogeneous medium, part of the wave energy is absorbed and turns into heat. In a heterogeneous medium, additional losses take place in the form of scattering. The attenuation coefficient is given by

$$\alpha = \alpha_a + \alpha_s \qquad (5)$$

where α_a *is* the absorption coefficient and α_s is the scattering coefficient.

In solids, absorption is dominated by elastic hysteresis and internal friction. These mechanisms have frequency dependence that is normally a linear function in solids. Scatter is due to inhomogeneities that depends on the wavelength and a characteristic impedance different from that of the surrounding materials, The scattering coefficient varies with the wavelength-to-diameter ratio of the inhomogeneities. In summary, the value of the velocities will be different for different soils

Experimental Setup

A schematic diagram of the setup designed and fabricated in the laboratory is shown in Fig. 1. It consists of a Panametrics pulser/receiver unit combining an impulse type pulser with a receiving system and the sample holder for the soil sample under investigation as well as an oscilloscope to accurately measure the travel time for the ultrasonic waves.

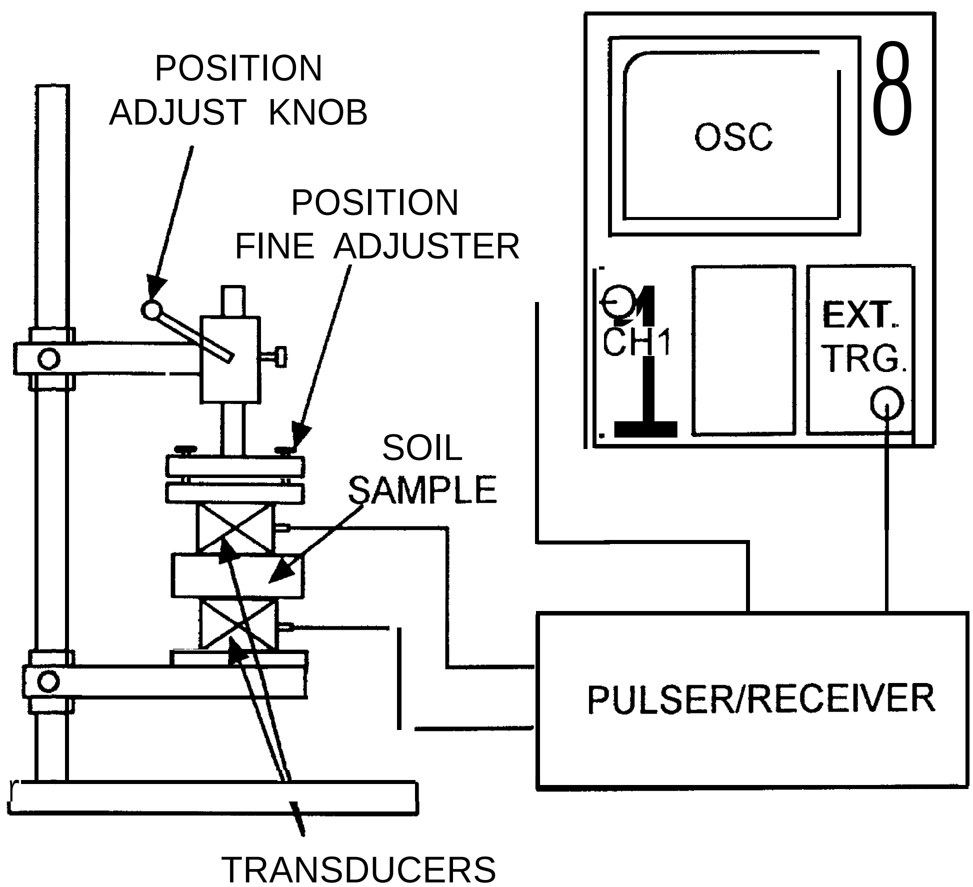


Fig. 1. “Experimental setup for measuring soil moisture using ultrasonic transducers

Two transducers are attached to a vertical support and the sample can be sandwiched between them. Coupling of the sample to the transducer has been found to be critical to control conduction of the sound between tranducer and sample. Normally coupling to the sample is accomplished by using a light weight oil, glycerin or other suitable couplant. In the present case, we have used dry contact coupling which introduces some uncertainties in the measurement. The analog recording system makes it difficult to determine the travel time accurately, The angle of incidence is kept perpendicular to the surface of the sample and the time of travel is measured. **A** transmitting 500 kHz transducer is connected to the pulser to apply electric pulses. The pulses are then converted to the ultrasonic signal in the transducer. The receiving transducer is connected to the receiver to amplify the received signal, This amplified signal is displayed on the oscilloscope screen.

For a typical measurement, the following procedure is followed:

(1) Two transducers are placed face to face (zero distance) and a reference peak is recorded,

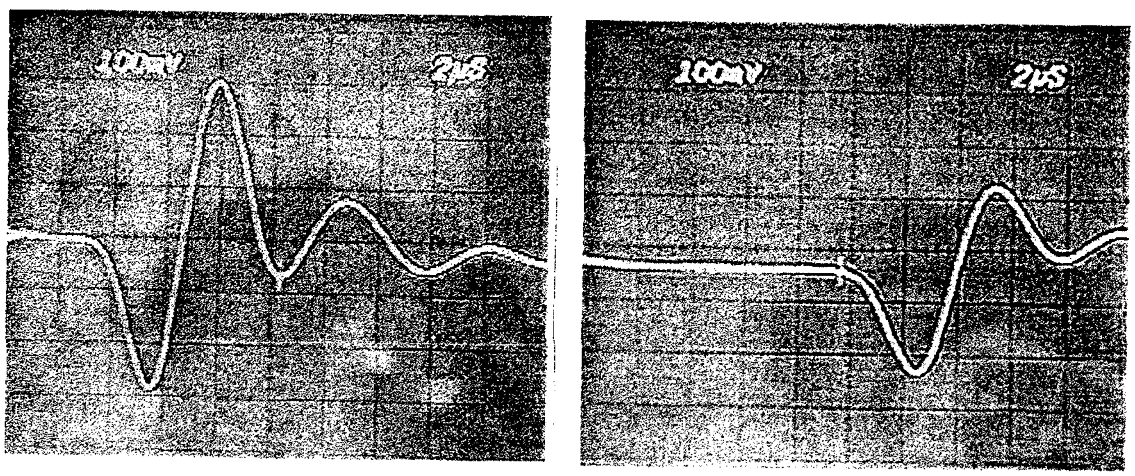
(2) A sample is placed between the transducers and one of the transducers is adjusted to get a maximum amplitude and symmetrical sinusoidal waves without distortions.

(3) A propagation time is calculated by reading the time between the reference peak and the peak from the received signal.

(4) Ultrasonic velocity is calculated using the propagation time and the length of the soil sample under investigation.

Results and Discussion

Preliminary results for the measurement of ultrasound velocities in Decatur soil are given in Table 1, and are calculated by measuring the time interval from the reference point on the oscilloscope screen, Fig. 2 below shows the oscilloscope traces for a) dry soil and b) wet soil.



(a) Dry Soil (b) Wet Soil

Fig. 2 Cathode Ray Oscilloscope traces to determine the travel time through the samples

Typical values of ultrasonic velocities in soils and other media are listed in Table 1.

Table 1. Typical measured ultrasonic velocities in soils and other media

Specimen	Sample Thickness (mm)	Time (μS)	Longitudinal Velocity (m/s)
Air	1.9	6.0	317.9
Water	11.2	7.2	1558.6
Decatur Soil (Dry) ,	3.3	4.85	676.1
Decatur Soil (Wet)	4.78	13.4	356.8

Different values of ultrasonic velocity have been found for different packing for the same composition and moisture content. Attenuation of the ultrasonic signal is a function of the particle size and hence may be used as a possible method for particle size determination. Results show a differential in ultrasonic velocity of 319.3 m/s between dry and 100% moist soil. These results are planned to be used for making a moisture sensor. The relationship between ultrasonic velocity and moisture content as a function of packing also needs to be studied, More research is needed to bring this technology to fruition and work is underway.

Acknowledgments

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