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PHYSICAL FOUNDATIONS OF ULTRASONIC TESTING AND TECHNOLOGY FOR DEFECT DETECTION

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Abstract. The paper discusses the physical foundations of ultrasonic testing, including propagation, reflection and refraction of acoustic waves, wavelength, frequency and amplitude, as well as longitudinal, shear, surface and Lamb waves. The operation of a piezoelectric transducer, generation of a probing pulse, registration of defect and back-wall echoes, and the role of refraction and critical angles are considered.

Keywords: ultrasound, ultrasonic testing, non-destructive testing, acoustic wave, frequency, wavelength, amplitude, piezoelectric transducer, defect, reflection, refraction, critical angle, Lamb wave.

Annotatsiya. Maqolada ultratovush nazorat usulining fizik asoslari, akustik to‘lqinlarning materiallarda tarqalishi, aks etishi va sinishi, to‘lqin uzunligi, chastota va amplituda kabi asosiy parametrlar hamda ko‘ndalang, bo‘ylama, sirt va Lamb to‘lqinlarining xususiyatlari yoritilgan. Piezoelektrik o‘zgartkich yordamida zondlovchi impulsni hosil qilish, nuqson va tub signallarini qayd etish, sinish hamda kritik burchaklarning nazoratdagi o‘rni tahlil qilinadi. Material taqdimotdagi ma’lumotlar asosida tizimlashtirildi.

Kalit so‘zlar: ultratovush, buzmasdan nazorat, akustik to‘lqin, chastota, to‘lqin uzunligi, amplituda, piezoelektrik o‘zgartkich, defekt, aks etish, sinish, kritik burchak, Lamb to‘lqini.

Non-destructive assessment of the internal condition of engineering materials and structures is an important area of modern diagnostics. Ultrasonic testing is based on transmitting an acoustic pulse into a material and analysing the signals reflected from boundaries and internal discontinuities. The method is based on the principles of acoustic wave reflection and refraction at the interface between two media.

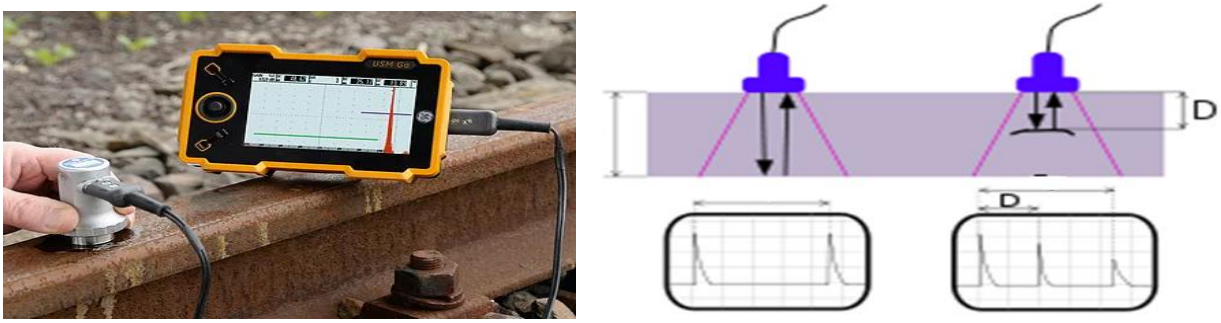


Figure 1. General principle of ultrasonic testing.

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Physical Nature of Ultrasound

Ultrasound consists of high-frequency mechanical vibrations that are generally beyond the range of human hearing. The frequency range presented in the article extends from 20,000 Hz to 100 MHz. Vibration refers to the repeated movement of particles in a medium around their equilibrium positions, while a wave describes the propagation of this vibration through space.

Main Acoustic Parameters

Wavelength λ is the distance travelled by an elastic wave during one complete cycle. Frequency f is the number of oscillations per unit of time.

$$\lambda = cT = c/f$$
$$f = 1/T$$
$$T = 1/f$$

Here, c is the velocity of ultrasound in the medium, T is the period, and f is the frequency. The article gives a vibration frequency of 2.5 MHz = 2,500,000 Hz as an example. Amplitude is the maximum displacement of the magnitude of vibration from its equilibrium position.

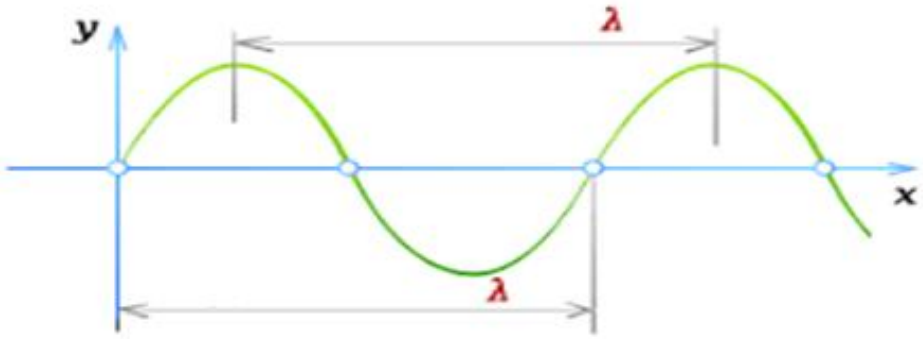


Figure 2. Wavelength.

Types of Ultrasonic Waves

The article describes shear, longitudinal, surface and Lamb waves. In a shear wave, particle vibration is perpendicular to the direction of propagation. In a longitudinal wave, the directions of vibration and propagation are the same. Surface waves propagate in a layer close to the material surface, whereas Lamb waves propagate in thin plates.

Wave type	Vibration	Propagation
Shear	Perpendicular	Mainly solids
Longitudinal	In the same direction	Solids, liquids, gases
Surface	Elliptical	Near the surface
Lamb	Along the plate	Thin plates

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Surface and Lamb Waves

The article indicates that the velocity of surface waves is approximately 8% lower than that of shear waves and that they propagate near the surface to a depth of approximately one wavelength. The velocity of Lamb waves depends on the plate thickness and the ultrasonic frequency.

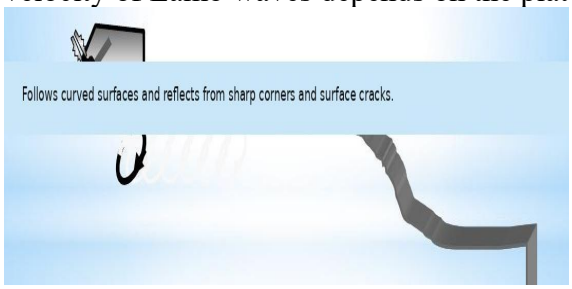


Figure 3. Surface waves.

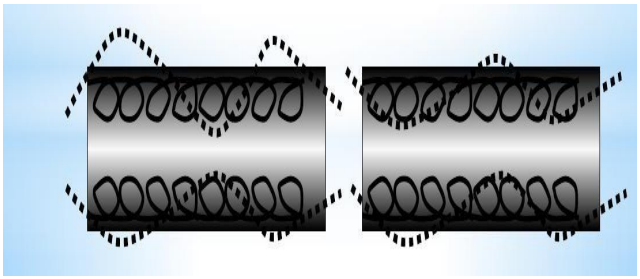


Figure 4. Lamb waves.

Reflection and Refraction at Interfaces Between Media

When ultrasound passes from one medium into another, part of it is reflected while the remaining part enters the second medium. Differences in the acoustic properties of the media affect the direction of wave propagation. The presentation illustrates processes at interfaces involving air, steel, water and organic glass.

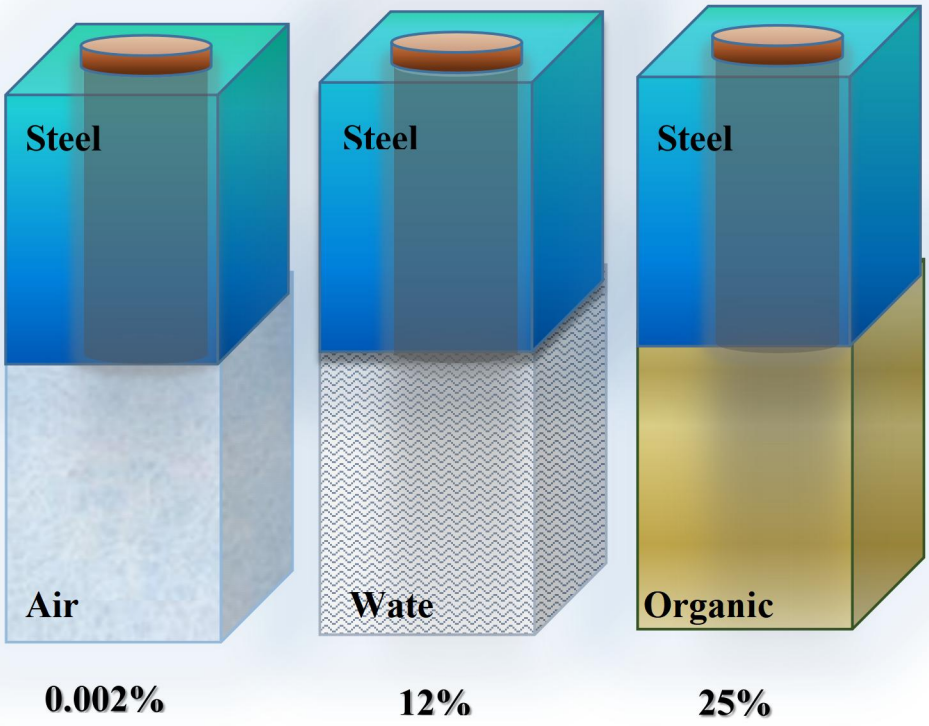


Figure 5. Propagation of ultrasound at interfaces between different media.

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Piezoelectric Transducer and the Pulse-Echo Method

A piezoelectric plate converts electrical energy into mechanical vibrations and converts returning mechanical vibrations into an electrical signal. The inspection signal is transmitted into the material. A signal reflected from an internal defect is observed as a defect echo, while a signal reflected from the opposite surface is observed as a back-wall echo.

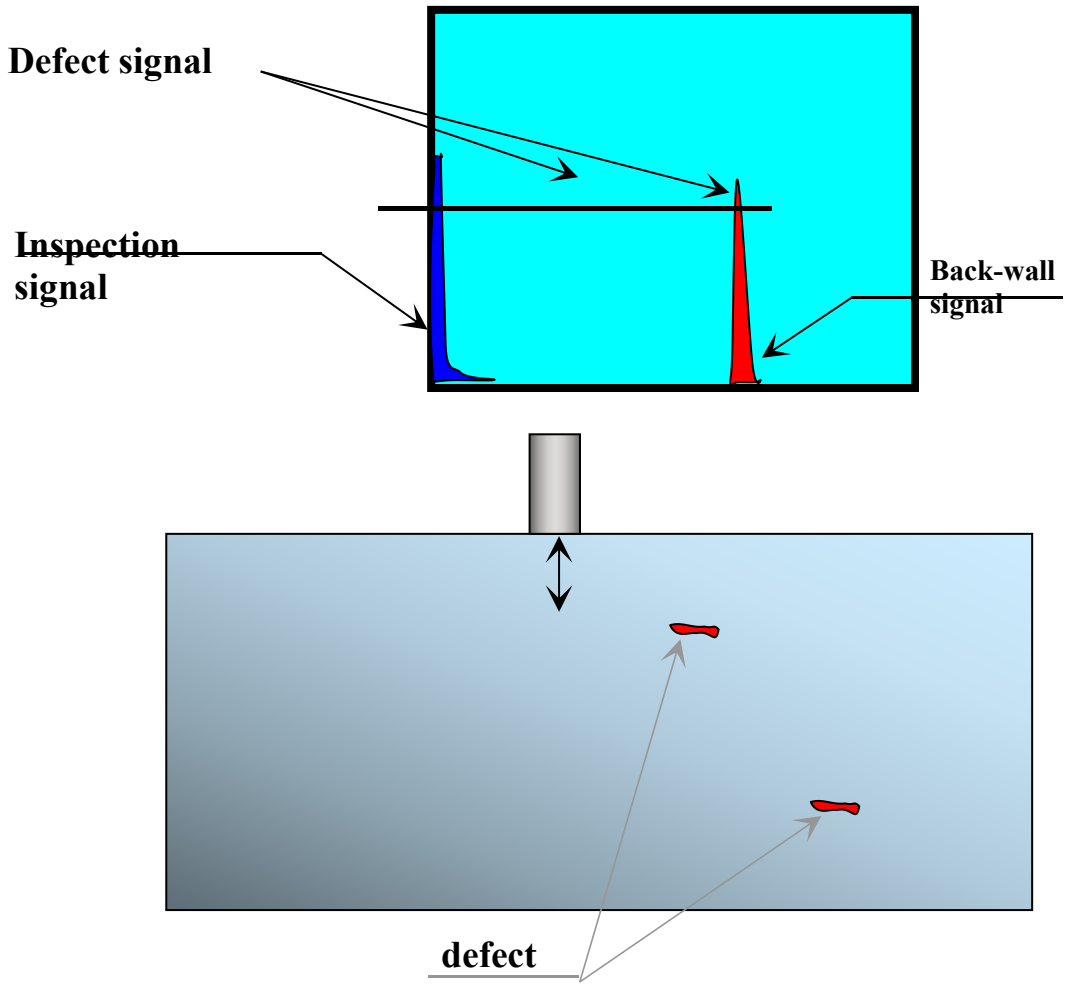


Figure 6. Inspection, defect and back-wall signals.

Estimation of Defect Depth

The delay time of the returned signal makes it possible to estimate the distance to a defect or reflecting boundary. For an ideal homogeneous medium and a straight-beam geometry:

$$h = ct/2$$

Here, h is the distance to the reflecting object, c is the velocity of ultrasound, and t is the signal round-trip time. In practical testing, the instrument settings and transducer geometry are taken into account.

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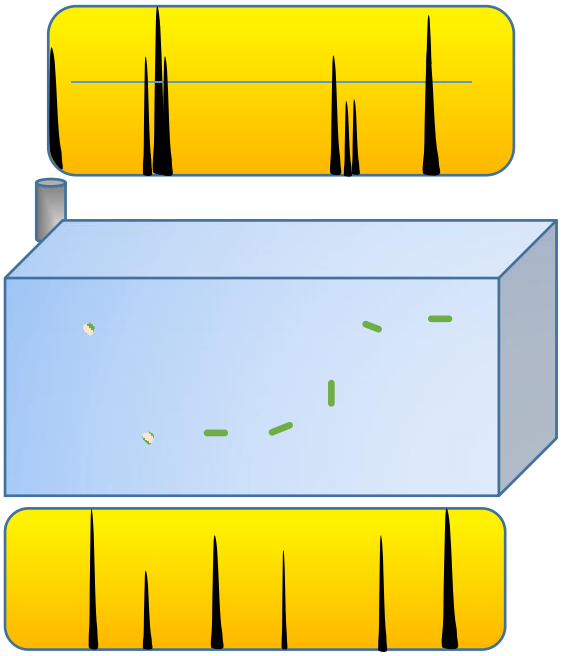


Figure 7. Returned signals on the flaw detector screen.

Refraction Angles and Critical Angles

The figure shows the angles α, β and γ. The direction of wave propagation changes because of the difference in velocities between the media. The general mathematical expression for refraction is:

$$\sin \alpha / c_2 = \sin \beta / c_1$$

Critical angles are associated with a change in the type of wave. The figure presents separate diagrams illustrating the first and second critical angles.

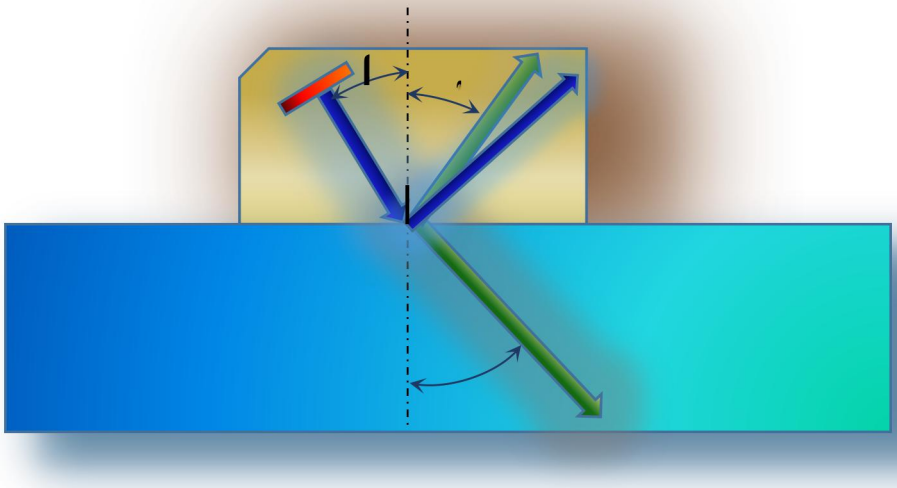


Figure 8. Angles of incidence and refraction.

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Defect Detection Technology

The general testing sequence is as follows: selecting and setting up the transducer; ensuring acoustic coupling; transmitting the inspection signal; propagation of the wave through the material; receiving the signal reflected from a defect; recording the signal on the flaw detector screen; and analysing the signal position and amplitude.

Reference Blocks

The study presents the CO-1, CO-2 and CO-3 reference blocks. They are shown as specimens used for setting up the testing system and checking measurement conditions.

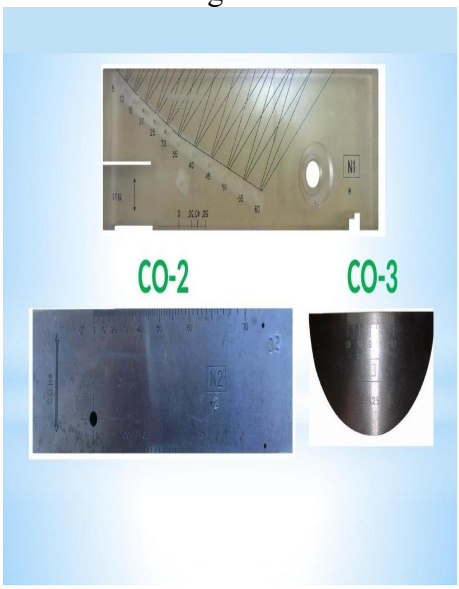


Figure 9. CO-1, CO-2 and CO-3 reference blocks.

Discussion

The material presented in the article describes ultrasonic testing as a unified physical and technological sequence: vibration → elastic wave → entry into the material → reflection/refraction → return of the signal from a defect → recording of the pulse on the flaw detector. When selecting the testing mode, the wave type, frequency, acoustic properties of the material, component geometry and expected defect orientation are considered in relation to one another.

ISO 16810:2024 specifies the general principles of ultrasonic testing of industrial products and requires the relevant product standard, technical specification or written procedure to be taken into account. ISO 17640:2018 covers techniques, testing levels and assessment for manual ultrasonic testing of metallic welded joints. ASTM E114-20 describes pulse-echo testing using straight-beam longitudinal waves.

Conclusion

Ultrasonic testing is a non-destructive testing technology based on the propagation, reflection, refraction and transformation of elastic acoustic waves. Its theoretical basis consists of frequency, period, wavelength and amplitude. A signal transmitted by a piezoelectric transducer propagates through the material and is reflected from a defect or the opposite surface. Analysis of the time and amplitude of the returned signal provides information about a reflecting object inside the material. The

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material presented in the article on wave types, angles, critical conditions, defect echoes and reference blocks consistently describes the physical and technological foundations of ultrasonic testing.

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