Understanding Ultrasonic Transducers

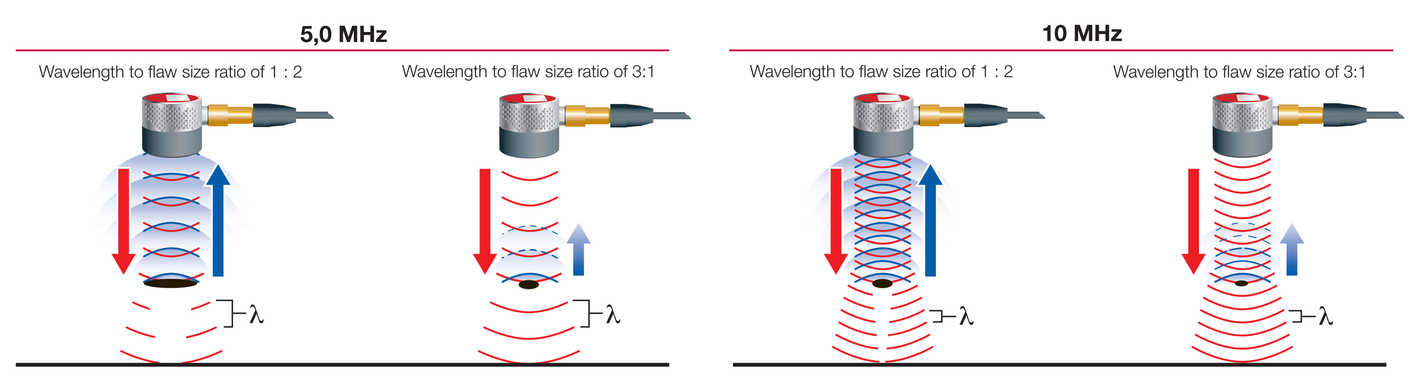
How to select a frequency

As the frequency increases, the wavelength decreases, enabling the detection of small flaws and thickness/location precision. As frequency decreases, the wavelength increases, enabling greater penetration into thick and/or attenuating materials. Other factors, such as nearfield length, beam spreading, and beam diameter, also affect frequency selection.

Common pulse-echo contact techniques, such as contact tests of fine-grained steels, generally utilize frequencies of 2.25 MHz to 5.0 MHz. Medium-carbon steel castings are generally tested between 1.0 MHz and 5.0 MHz. High-carbon and high-alloy steels can require lower frequencies in the range of 0.5 MHz to 1.0 MHz. Tests on thin plastics and ceramics utilize frequencies of 20 MHz and higher. As a general rule, the wavelength should be equal to or smaller than the minimum size flaw that must be detected.

$$\lambda = \frac{c}{f}$$

Where: λ =wavelength
c =material sound velocity
f =frequency



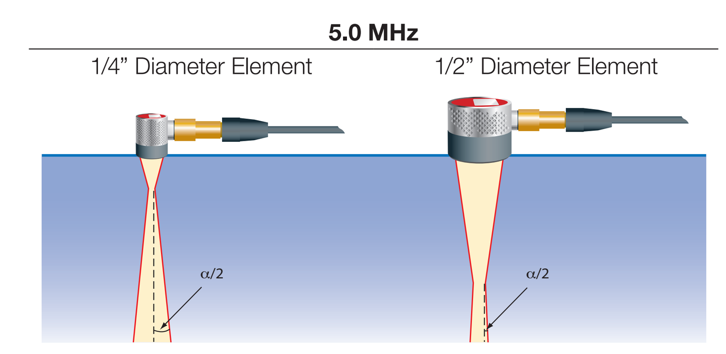
As frequency increases, wavelength decreases, improving the sensitivity to small flaws.

Is element diameter important?

Coverage area is an important factor to consider when choosing the transducer element diameter. Beam spread, or the angle at which the sound beam diverges after the nearfield, also needs to be considered. It is related to the element diameter, the material sound velocity, and the frequency through the following formula:

$$\sin(\alpha/2) = \frac{0.514c}{fD}$$

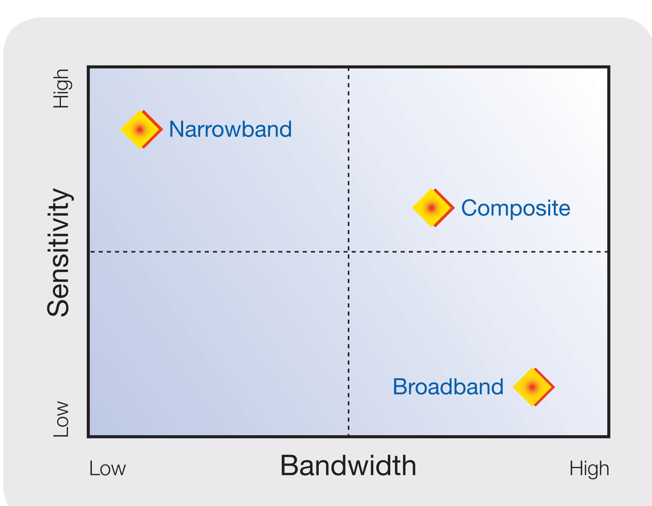
Where: α = beam spread angle
c = material sound velocity
f = frequency
D = element diameter



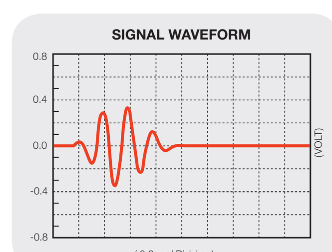
The effect of element diameter on beam shape.

Why does bandwidth matter?

The bandwidth of a transducer defines its frequency output, which, in turn, affects its performance. The bandwidth is commonly defined as the span between the minimum and maximum frequencies that occur in the spectrum at –6 dB amplitude from the center frequency. Narrow bandwidth often improves sensitivity, while broad bandwidth improves near-surface resolution.

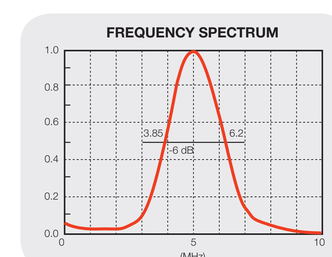


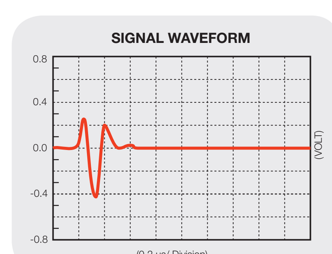
A comparison of transducer performance.



Narrowband Transducers

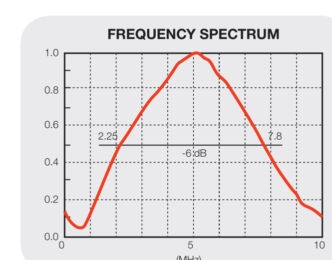
A narrowband transducer has a narrower frequency spectrum and longer ringdown due to the lightly damped design of the transducer, which makes it more sensitive to reflections from smaller indications. These are used for applications such as flaw detection and flaw sizing.

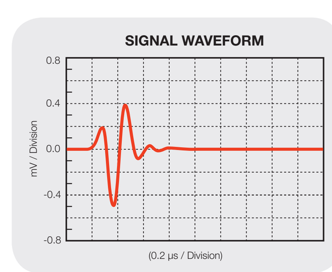




Broadband Transducers

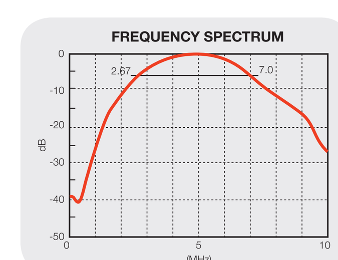
A broadband transducer has a broader frequency spectrum and a shorter ringdown time due to the heavily damped design, which improves near-surface and axial resolution. These transducers are commonly used for applications such as thickness gaging, sound velocity measurements, and time-of-flight diffraction techniques.

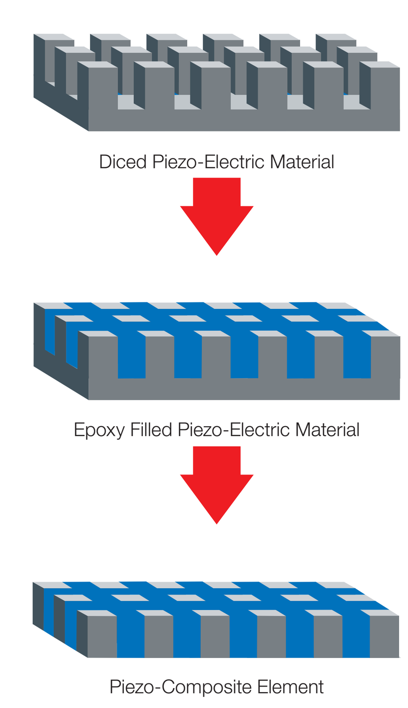




Composite Transducers

A composite transducer element is made from a standard element that is diced and filled with epoxy, changing its mechanical and electrical properties. This results in a transducer that has a combination of broad bandwidth and high sensitivity. Composite elements have a low acoustic impedance, which results in a more efficient energy transfer to other low impedance materials. Composites are advantageous for detecting flaws in attenuating materials that require good near-surface resolution, high sensitivity, and high signal-to-noise ratios.





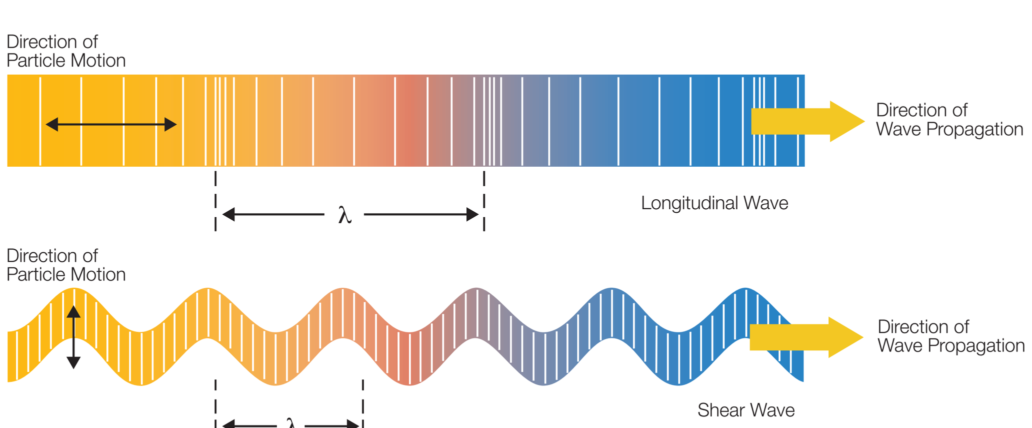
Steps in making a piezo-composite element.

Is wave mode important?

A wave mode is defined by the motion of the molecules within a sample. The two most common wave modes that are utilized in ultrasonic NDT are longitudinal waves and shear waves. These two modes travel at different sound speeds within a material. The shear mode wavelength is typically close to 1/2 the wavelength of the longitudinal mode at a given frequency.

Longitudinal – In this mode, particles move in the same direction as the wave is traveling. Longitudinal waves are used for most thickness gaging and straight beam flaw detection applications as well as angle beam flaw detection in coarse grained materials, such as cast stainless steel, where shorter wavelengths are unable to penetrate.

Shear – In this mode, particles move perpendicular to the direction the wave is traveling. Since the shear wave wavelength is generally about 1/2 the wavelength of the longitudinal wave, smaller flaws can be located at a given frequency. Shear waves are used to improve detection of small reflectors in angle beam flaw detection as well as to determine shear wave velocity components for material characterization.



Comparison of particle motion in longitudinal and shear wave modes.

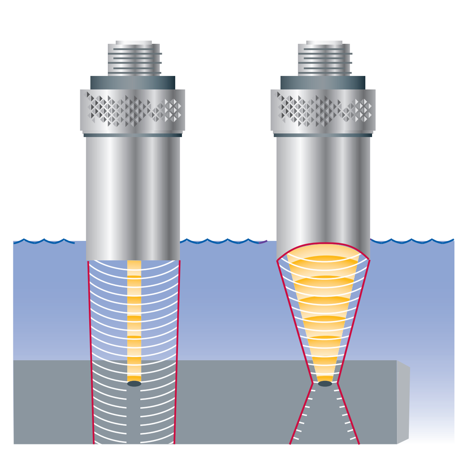
What does focusing do?

In the case of a flat-faced transducer, the transducer's nearfield limit is considered the natural focus of the beam. It is the point where the greatest amount of sound energy per unit area is found and will produce the maximum echo from a target or reflector. Immersion transducers can be focused using a lens to increase the concentration of sound energy at the focal point. If the sound energy is focused to a smaller beam diameter, more of the output energy of the transducer will reflect from a small indication. Transducers can be focused both spherically and cylindrically.

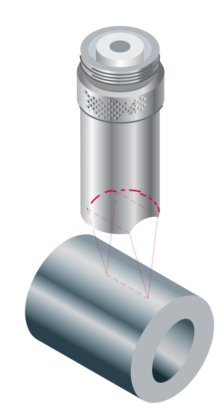
Beam diameter is related to focal length, material sound velocity, frequency, and element diameter by the following formula:

$$BD\ (-6\ dB) = \frac{1.02\ Fc}{fD}$$

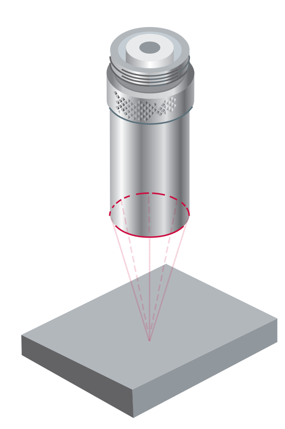
Where: BD = beam diameter
F = focal length
c = material sound velocity
f = frequency
D = element diameter



Effect of focusing on reflected acoustic energy.



Beam shape of cylindrical focus.



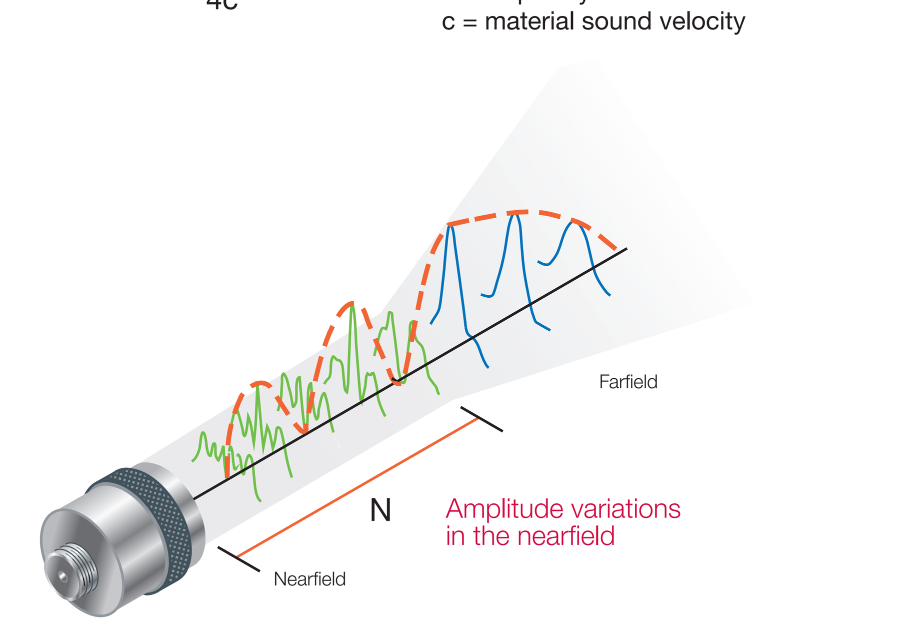
Beam shape of spherical focus.

What effect does nearfield have?

The nearfield is the region directly in front of the transducer where the echo amplitude varies widely due to constructive and destructive interference from the vibrating active element. The end of the nearfield is the natural focus of the transducer and is the point where the sound field reaches an amplitude maximum, after which the sound field pressure begins a gradual drop to zero. Nearfield length is related to the element diameter, the frequency, and the material sound velocity by the following formula:

$$N = \frac{D^2 f}{4c}$$

Where: N = nearfield
D = element diameter
f = frequency
c = material sound velocity



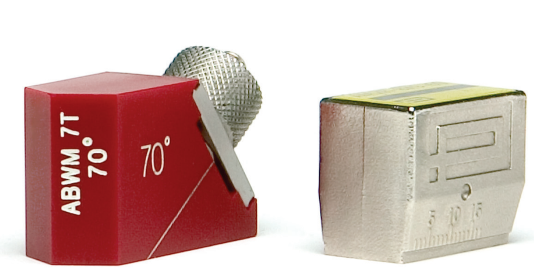
Probe Types

Dual

This transducer uses separate transmitting and receiving elements to create a pseudo-focus, which is advantageous for inspecting parts with rough backwall surfaces. Applications include remaining wall thickness measurements, corrosion/erosion monitoring, and high temperature applications.

Contact

Intended for direct contact with a test piece, this transducer typically has a hard wear surface optimized for contact with most metals. Applications include straight beam flaw detection, thickness gaging, and velocity measurements.



Angle Beam

The removable or integral wedge of an angle beam transducer introduces sound at an angle into the part. The main applications are weld inspection and other flaw detection and crack sizing techniques, including time-of-flight diffraction.

Delay Line

Utilizing an additional piece of material called a delay line in between the transducer and test material separates echoes from excitation pulse recovery and/or insulates the transducer element from heat. Applications include thickness gaging and flaw detection of thin materials, as well as high temperature applications.

Immersion

Immersion probes are intended for use on a test piece that is partially or wholly immersed in water. The water acts as a uniform couplant as well as a liquid delay line. This transducer is optimal for automated scanning, in-line thickness gaging, and high-speed flaw detection and can also be focused for improved sensitivity to small reflectors.

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