Physics of Ultrasound

Sixth lecture

Ultrasound Beam Shape

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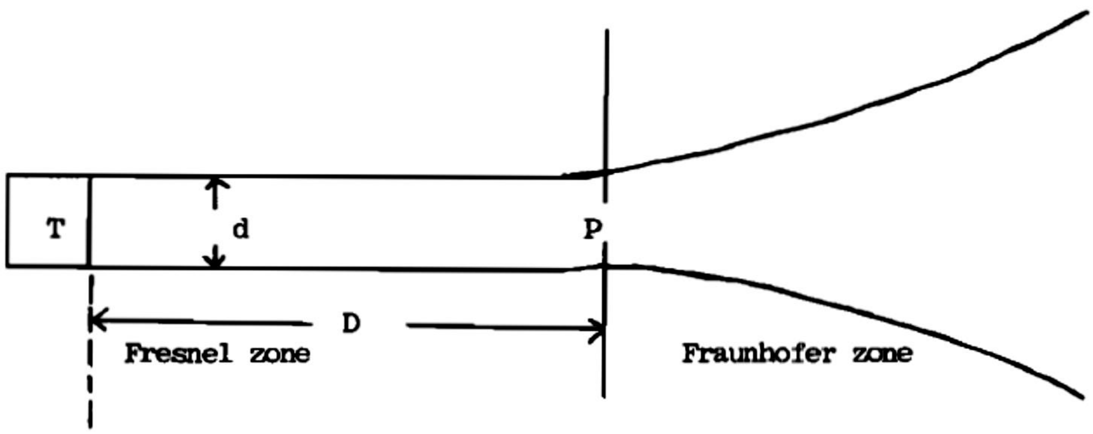
1. *Introduction*

- As a beam of ultrasound travels outwards from the surface of the transducer, the distribution in space of the ultrasonic energy undergoes change.
- Axially, the intensity of the beam diminishes gradually with distance along the central axis of the beam, while
- Laterally, at any plane perpendicular to the beam direction, the intensity decreases rapidly with distance from the central axis.
- Generally, the ultrasound beam spreads out, or undergoes divergence, as it moves away from the transducer.
- The term "ultrasound beam shape" is commonly used to describe the manner in which the spatial distribution of the beam changes with distance from the source.
- The beam shape has very significant effects on the quality of the ultrasonic image, and on the tissue depths that can be usefully interrogated using a particular beam. This section examines the factors which influence ultrasound beam shape, and the associated implications for ultrasonic imaging.

2. *General shape of the ultrasound beam*

- The typical manner in which the ultrasound beam spreads out with increasing distance from the transducer, T, is shown in Fig



General shape of the ultrasound beam

- Initially, between T and the plane P along the beam path, the beam is narrow, with a small beam width, d, equal to about the diameter of the piezoelectric crystal. This part of the beam is referred to as the near field, or the Fresnel zone.
- Beyond P, the beam spreads out (diverges) over a larger and larger area, with increasing beam widths which result in a rapid deterioration of spatial resolution of the image. This part of the beam is known as the far field, or the Fraunhofer zone.
- The distance from the transducer to the plane P is sometimes called the transition distance (in reference to the change from Fresnel zone to Fraunhofer zone).
- The length, D, of the Fresnel zone, and the beam width, d, at a given plane across the beam, are important parameters which influence, respectively, the practical tissue depth that can be interrogated with the beam, and the spatial resolution in the ultrasonic image.
- The narrow beam associated with the near field is desirable for good spatial resolution. The length of this part of the beam therefore determines the approximate tissue depth which, in practice, can be investigated using the beam.

3. *Factors influencing beam shape*

The shape of the ultrasound beam is affected by:

- ✓ The size and shape of the ultrasound source
- ✓ The beam frequency,
- ✓ beam focusing

3.1 Effect of source size

✓ The size of the ultrasound source affects the beam width, the length of the Fresnel zone, and the angle of divergence beyond the near field.

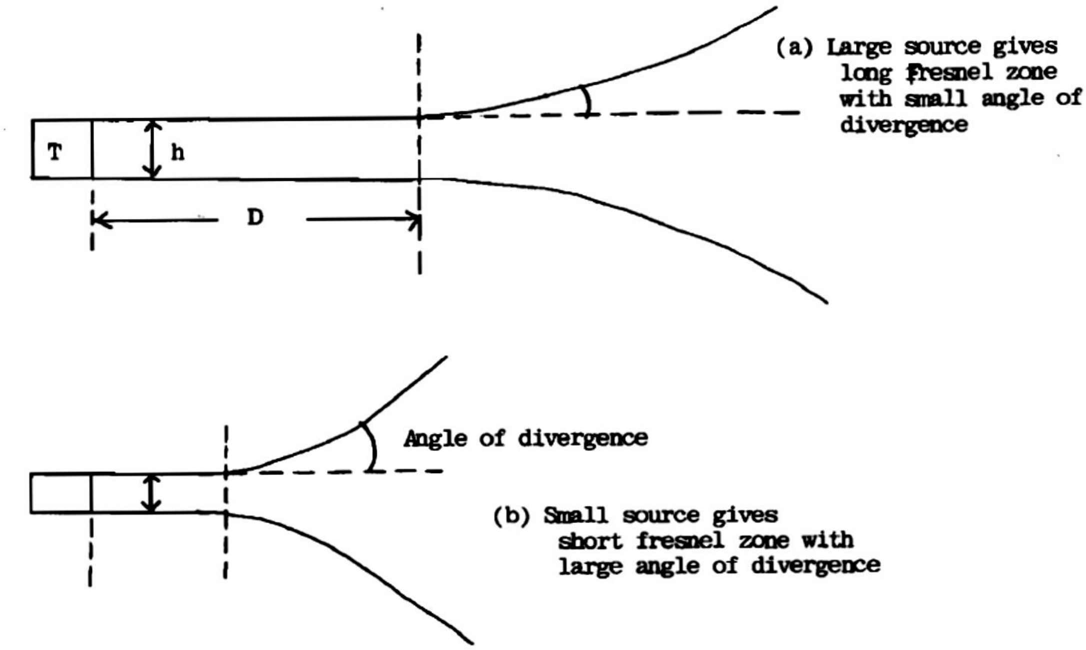
✓ For a transducer in which no focusing is applied, the length, D, of the Fresnel zone is determined by the diameter of the transducer and the wavelength of the ultrasound beam according to the relation:

$$D = \frac{r^2}{\lambda} = \frac{d^2}{4\lambda} \quad \text{...............(1)}$$

where r = radius of the transducer, λ = wavelength of the ultrasound beam and d = 2r is the diameter of the transducer.

✓ Within the near field, the beam width is approximately equal to the transducer diameter.

✓ the length of the Fresnel zone increases rapidly as the beam width (or transducer diameter) is increased.



Variation of length of Fresnel zone and angle of divergence with source diameter

- Conversely, the length of the Fresnel zone diminishes rapidly as the transducer diameter is reduced.

- In addition, a small transducer diameter results in a large angle of divergence beyond the near field (see Figs. (a) and (b)), thereby diminishing the lateral resolution rapidly

In summary, the effects of source size on beam shape are:

(i) a small source provides a narrow beam initially, is associated with a short Fresnel zone, and the beam diverges rapidly beyond the near field.

(ii) a large source provides a broader beam initially, gives a longer Fresnel zone, and the beam diverges more gradually, thus providing better resolution of deeper structures.

3.2 Effect of beam frequency

- Eq 1 can be modified by substituting the wavelength of the ultrasound beam by

$$\lambda = v/f$$

where v = velocity of ultrasound in the transmitting medium,

and f = beam frequency.

$$\text{Then we get } D = \frac{d^2}{4\lambda} = \frac{d^2 f}{4v}$$

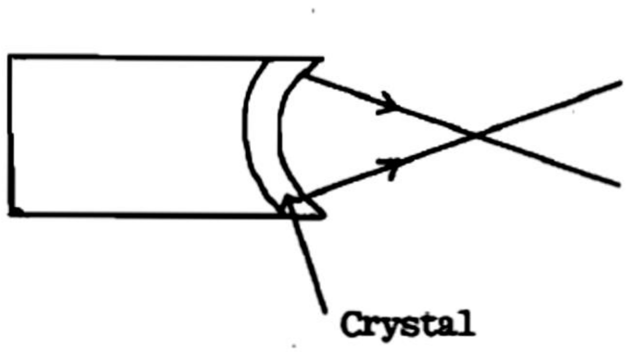
The length of the Fresnel zone increases as the beam frequency is increased.

3.3 Focusing of the ultrasound beam

- The shape of the ultrasound beam can be influenced to varying extents by applying different focusing methods

✓ *Shape of the crystal element*

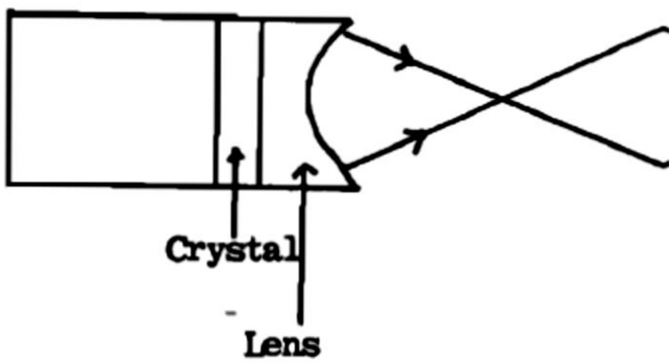
The crystal element can be suitably shaped by concave curvature to focus the ultrasound beam. This is an internal focusing method, because it is affected in the crystal itself. The degree of focusing will depend on the extent of curvature (radius of curvature) of the crystal.



Concave shape of crystal

- *Acoustic lenses*

Acoustic lenses made from materials which propagate ultrasound at velocities different from that in soft tissue can be used to focus the beam by refraction. The lens will have concave curvature, and the degree of focusing will be determined by the radius of curvature of the lens.

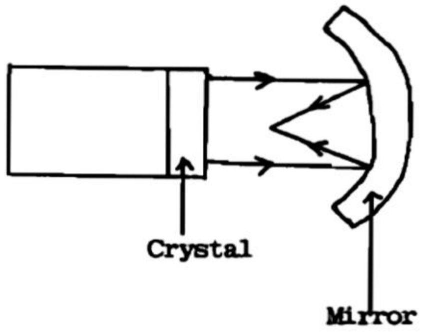


Acoustic lens

- *Acoustic mirrors*

A concave mirror can be used to focus ultrasound by reflection Again, the degree of focusing will depend on the radius of curvature. Acoustic lenses and mirrors provide external focusing.

Acoustic mirror

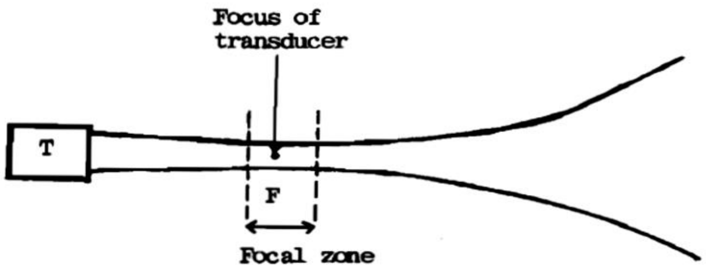


✓ *Electronic focusing*

Electronic focusing is employed in multi-crystal transducers. Electronic focusing offers the advantage of providing variable focus, or dynamic focus, as opposed to the other methods which provide fixed focus.

✓ *Focus of a transducer, focal zone*

The focus, F, of a transducer is that point along the central axis of the beam which is equidistant in time from all points on the surface of the transducer. The times of flight of the ultrasound waves are equal for all linear paths between the surfaces of the transducer and F. The region around F over which these conditions prevail is called the focal zone of the transducer



Shape of focused beam, showing the focal zone.

Classification of focusing

The degree of focusing may be classified into three categories as follows:

- ✓ strong focusing (or short focusing)
- ✓ medium focusing
- ✓ weak focusing (or long focusing)