PHENOMENON OF ULTRASONIC DISTORTIONS

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ABSTRACT :

As the ultrasonic image is constructed by the reflected echoes from the interfaces between two different densities (tissues, materials or bodies) , thus the study of the characteristics and behaviour of the emitted and the refelcted ultrasonic beam is the key of its effecient use .
This paper investigates the phenomenon of ultrasound which produces distortions and discusses the factors affecting the resolution owing to the properties of the wave's propagation and the principle of the scanning process. It suggests a technical method to obtain the accurate coordinates of the image points in spite of the distrotion's existance .

INTRODUCTION :

The ultrasonic waves have the ability of penetration through different materials or tissues and be reflected at their boundaries. They are emitted in very short pulses by a transducer able to receive the reflected echoes between pulses and transforms them into electrical energy. The voltage generated is proportional to the intensity of each returning wave . Echoes are then detected and analysed before being displayed on a screen as different degrees of grey relatively to their amplitudes .

The geometric fidelity of the acoustic imageries depends on the distortions occured by the ultrasonic system and its resolution . The greater the resolution, the more detailed information can be extracted from the image and the less the distortions, the more exact are the locations of the image's points .
The distortions occured on the ultrasonography are the result of the *physical reaction* between two main items :
* *The generated U. S. beam* which is function of the wave's   properties and the transducer's diameter .
* *The nature of the photographed body*, mainly its density,   its surface's orientation and roughness, which controls the   intensity of the reflected echoes .

THE PROPERTIES OF ULTRASONIC BEAM AFFECTING ITS RESOULTION :

The ultrasound waves are sharing many properties with light. They may be generated electrically, focused and collimated into a beam. They obey the optical laws of reflection and refraction as they pass through the boundaries between transparent media of different characteristics or densities. The resolution of the generated beam is determined by the combination of different wave's parameters as the frequency F, the intensity I, the wavelength and the transducer's diameter, in addition to the length of the emitted pulse .

FREQUENCY AND WAVELENGTH :

The wavelength λ, velocity V and the frequency F of a sound wave are related by the following equation :

$$V = F . \lambda$$

Since V is considered constant and equals the velocity of the ultrasound in water = 1540 m/ sec., an increase in frequency results a smaller sound wave length ; for example, for a frequency of 2 MHZ (million hertz) :

$$\lambda = \frac{V}{F} = \frac{1540}{2 \times 10^6} \ m = 0.77 \ mm$$

The wavelength determines the limit of resolution for the system, since structures closer together than one wavelength cannot be identified as two separate identities, therefore, at higher frequencies, the wave lengthes become correspondingly shorter which increases the resolution of the system. But the disadvantage of increasing frequency is that the sound beam is strongly attenuated, this is important for measurements of small thicknesses or for high resolution flow detection .

INTENSITY AND DEPTH PENETRATION :

Ultrasonic applications are rigidly classified as being of either low or high intensity. At low intensity, ultrasound is, used as a mean of investigating the properties of the materials samples or as a method of control .
Higher intensity applications are nearly always made at low frequencies (often just above the audible limit) , and acoustic powers may extend from a few milliwatts to kilowatts, it can cause a permanent changing in the structural and chemical properties of the materials .
The intensity of the sound beam constantly decreases as it passes through tissues due to the effect of absorption and reflection .
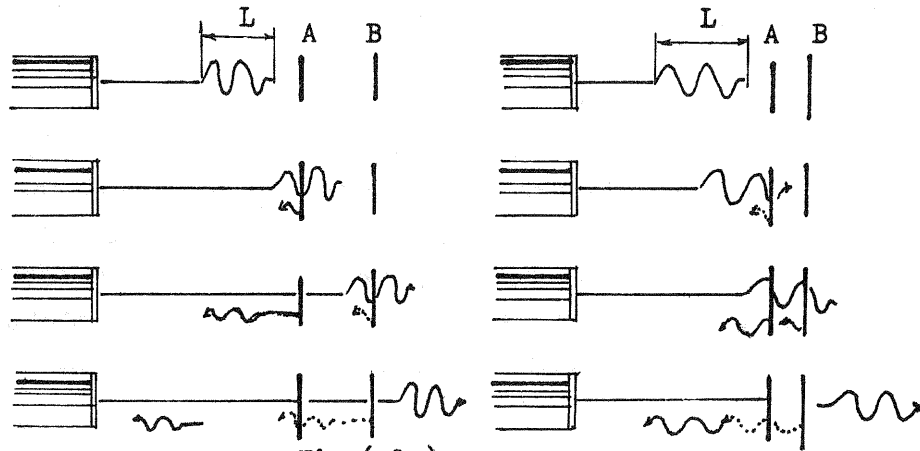
Fig (1)
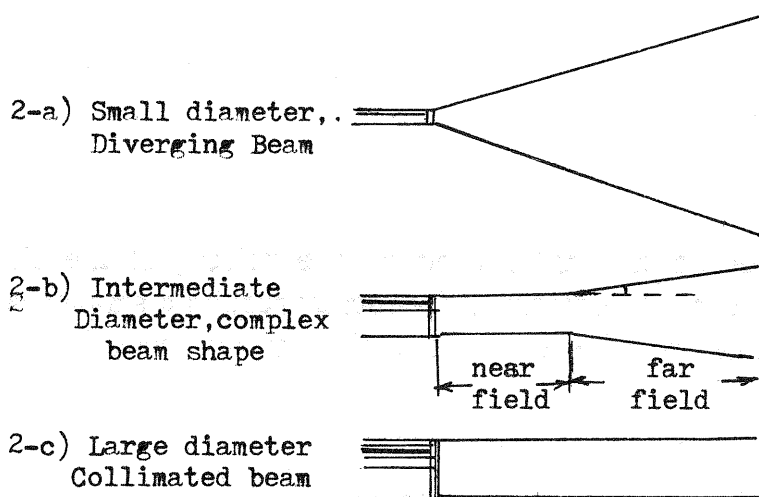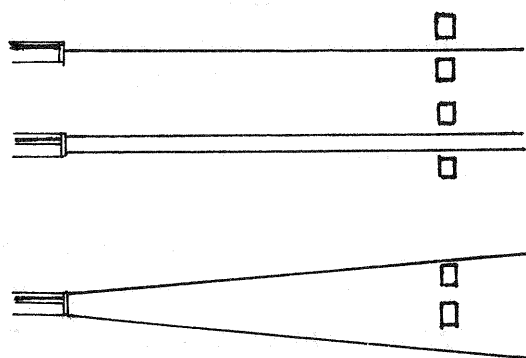
The Effect of Pulse Length on Longitudinal Resolution

2-a) Small diameter,.
    Diverging Beam

2-b) Intermediate
    Diameter,complex
    beam shape

near
field

far
field

2-c) Large diameter
    Collimated beam

Fig (2)

Fig (3)

Effect of Beam Width on Lateral Resolution

LONGITUDINAL AND LATERAL RESOLUTIONS:

The longitudinal resolution of a system cannot be better than one wavelength which has a range of 0.1-1.5 mm for frequencies ranging from 1 to 15 MHZ (used for medical instruments) .
Fig. (1) shows the effect of the pulse length on the longitudinal resolution:the shorter the pulse length, the better is the resolution .
Better lateral resolution is obtained from narrow sound beam.
The beam width is dependent on the frequency and the crystal diameter of the transducer. The higher the wave frequency and the larger the diameter of the crystal, the less the divergence of the beam, as illustrated in Fig. (2) .
Fig. (3) demonstrates the effect of beam width on lateral resolution.
In all cases, lateral resolution is poorer than the depth resolution .

THE REFLECTED ECHOES :

The characteristics and behaviour of the ultrasound reflection from tissues of different densities within the body are the key of the use of Ultrasound .
The *reflection* depends on the difference in densities and *acoustic impedances* between the two internal bodies and upon the orientation of the reflecting surfaces, in addition to the effective role of the *absorption coefficient*.

THE ABSORPTION COEFFICIENT :

It is the amount of energy that the sound beam loses as it passes through 1 cm of the medium. It increases with increasing sound frequency and the rigidity of the tissues. For example , bones absorb approximately ten times more than the most soft tissues and these in turn absorb approximately ten times more than body fluids such as blood and urine .
Experimental measurements show that, at least over a limited frequency range, the absorption coefficient for soft tissues is proportional to frequency, for non biological fluids such as water, the dependance is proportional to F^2 .

ACOUSTIC IMPEDANCE AND REFLECTION :

When an ultrasound bean strikes the interface of two media of different acoustic impedances a portion of the incident wave is reflected back and the remainder will continue in the forward direction .
The acoustic impedance of a material Z is defined as the product of the denesity of tissue ρ and the sound speed in the material V .

$$Z = \rho . V \quad g/cm^2 \sec \text{ (rayl)}$$

For Longitudinal waves striking a plane interface prependicularly ; the percentage of reflected energy is given by the formula :

$$\% \text{ reflected} = \left[\frac{Z_2 - Z_1}{Z_2 + Z_1} \right]^2 \times 100$$

Where Z_1 & Z_2 are the acoustic impedances of the two media .

The intensity of the reflected echoes is controlled by the following conditions :

* Reflection occurs only at the boundaries between different tissues .
* Maximal reflections are from surfaces at or near right angles to the ultrasound beam, otherwise the angle of incidence will equal the angle of reflection and the reflected echoes will drop off in amplitudes .
* The rough interfaces scatter the ultrasound beam randomly so that the returned echoe is less dependent on the angle of incidence .
* Ultrasound does not propagate through air or dense bone .
* Because of the very low acoustic impedance of air (0.0004 rayl x 10^{-5}) , there is almost total reflection (99.99%) at an tissue.air interface .
  When an air gap is interposed between two tissues, there is no echo from the second tissue since almost 100% of the energy has been reflected, leaving none to penetrate .
* Due to the high acoustic impedance of the bone (7.8×10^{-5} rayl) approximately 50% of the incident energy is reflected but the rate of absorption in bone is so high that the result is the same .

THE ULTRASONIC DISTORTIONS :

The generation of the U.S. waves occurs in the form of a series of spherical pressure waves emerged from the transducer's face in the plan perpendicular to it in a longitudinal direction .

If any point A or pin of the Test Model, shown by Fig. (5) , is lying on the wave generation's plane, it will be submitted to the effect of the ultrasonic waves during the trajectory of the transducer from position (P_1) to position (P_3), thus the reflection of the waves from point A continues for a certain time as long as it remains in the field of the wave's generation. This duration of reflection involves that the image point A' is displayed as a curved line instead of a point, as Fig. (4) demonstrates it , (distortions are enlarged) .

This phenomenon is the source of the lateral distortions which are parallel to the transducer's face . If the last one is horizontal, each point appears as a horizontal curved line on the acoustic photography .
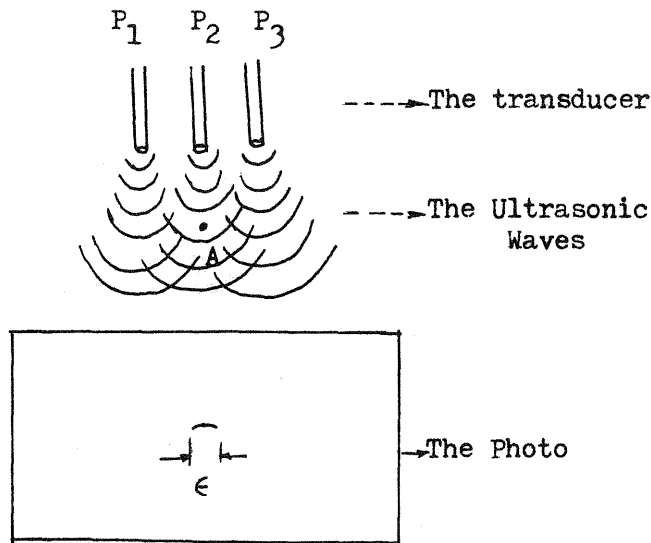
Fig (4)
The Ultrasonic Distortion
(magnified)

The distortion depends on many factors such as the reflection's duration, the beam divergence which is function of the transducer's diameter, the frequency and the distance y between the transducer and the point A. Fig. (6.a) illustrates a Polaroid photography of the Test Model, showing that the distortions at the top, nearer the transducer's face are less than those at the bottom .

When the transducer face is horizontal , ϵ occurs through the x direction. Since it depends on the duration of reflection, i.e. the time at which the pin A is exposed or lying in the focus of generation of the waves :

$$\epsilon \propto T$$

or $\qquad T \propto D \text{ (distance)} , \qquad$ since V is considered constant .

then $\epsilon \propto D$

$$\epsilon = m . D$$

$$\epsilon = m_1 x + m_2 . y$$

Where $m_1 x$ accounts the effect of the transducer's diameter and the frequency .

y is the vertical distance between the transducer's and the point A .

$m_2 y$ is introduced to compensate the effect of the sound beam divergence which increases as far as y increases .

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The Scan
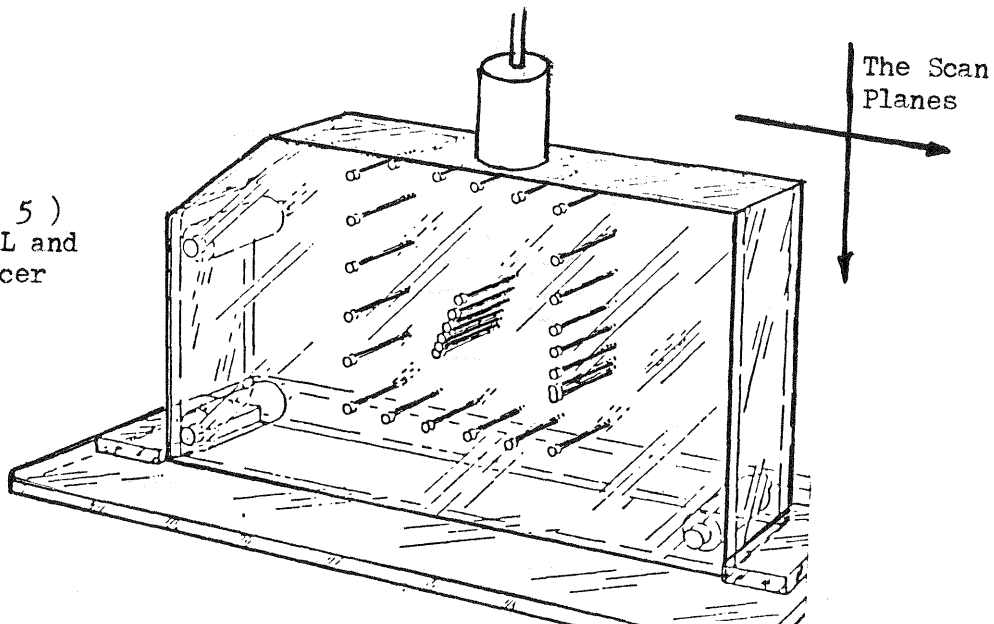Planes

Fig (5)
The Test MODEL and
The Transducer

Fig (6-a)
Polaroid Photogra-
phy of scanning
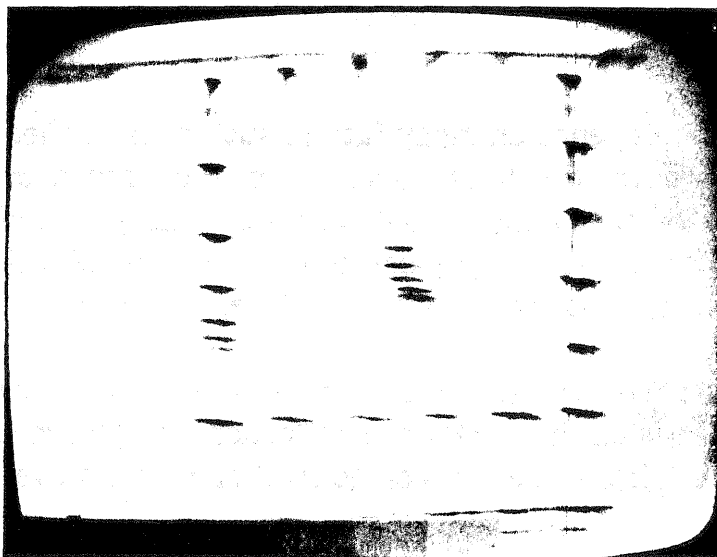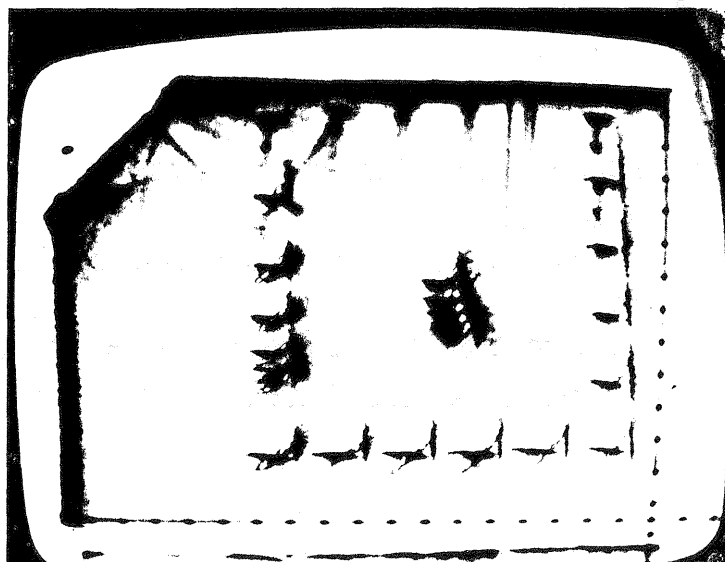the Test Model
from the upper
edge

Fig (6-b)
Polaroid Photogra-
phy of the Double
scanning of the
Model from the
Top and Right
sides.

TECHNICAL METHODS OF ERROR COMPENSATION :

The previous investigation showed that the ultrasonic distortions occurs mainly through the x direction for a horizontal position of the transducer face. And due to the fact that the points are displayed as horizontal lines, their x coordinates cannot be identified, but the y coordinates may be considered relatively correct .

To compensate the errors resulting from that phenomenon and to determine the x point's coordinates, one may use one of the following technical methods:

1. *Method* : Since the ϵ distortion is symmetrical with respect to the point A, regarding to the same wave's conditions forward and backward the pin , (P_2) the x coordinate may be determined as the middle of the distorted line with a considerable accuracy .

2. *Method* : The Test Model may be double displayed as shown in Fig. (6-b).
   - Once from the upper edge, each point is then displayed as a horizontal line and so, its y coordinate can be measured accurately .
   - Secondly, the transducer is moved vertically along the right side, every point is displayed again as vertical line . The x coordinates which become now in the direction prependicular to the transducer's face (and not parallel) may be accurately determinated .

Note :

The vertical lines may not intersect with the horizontal ones, this may be explained as follows :
* The distance between the square skeleton of pins in the second phase is larger than the similar distance in the first case . This involves that all the second scan is shifted, but with keeping the same relative horizontal distances which may be measured from the photo if any pin is considered as the origine .

REFERENCES :

Wishahy A. Zeinab : " Refinement of Photographs Obtained from U.S. Instruments by An Oscilloscope Camera " Unpublished Ph. D. Dissertation, Department of Civil Engineering, Cairo Univ. 1985 .