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DEFINITION AND CHARACTERIZATION OF FOCUSED BEAMS.

PRACTICAL ASPECTS.

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SUMMARY : Characterization of ultrasonic beams by means of echos coming back from targets is very often used. Results are not independant of shape and size of those targets. Measuring echos from inclined disk-like targets let appear fluctuating results in the very front part of beams.

List of symbols :

D	Diameter of the probe
F_{ac}	Focal distance with respect to the maximum of amplitude
F_{opt}	Focal distance with respect to center of equiphase surfaces
λ	Wavelength
x, y, z	Coordinates of a point with respect to transducer center
α	Inclination of target

I. INTRODUCTION

Improved precision of ultrasonic NDT needs well-known characteristics of the acoustic field that is used.

The way of field characterization have an influence on both validity domain of testings, and precision of results.To be able to give to end users simple and indisputable criterion to define usable acoustic field, it is essential to clear up the influence of numerous parameters : shape (ball, disc, cylinder) and size of the reflector, frequency, band-width, etc.

When measuring the variation of echo send back by disc-like targets as a function of the angle of incidence, we brought to the fore some differences between results, according to the characterization method that is used. Those differences are partially explained.

II. DEFINITION OF FOCAL DISTANCE, DIAMETER AND LENGTH OG BEAMS :

1. Definition of focal distance :

Definition of this parameter could seam to be quite simple, but is not un-ambiguous. At lesat four definition could be given :

1.1. F_{opt} : Like in optics, focal point is defined as the center of spherical wave produced by the focused transducer. In practice, F_{opt} is calculable only by probe manufacturer because precise determination of sound velocity in lense material is needed. That distance is mamed "optical focal distance".

1.2. Definition by echos : Three more definitions refer to maximum echo send back by a target placed on the axis of the beam. That target could be :

1.2.1. : a ball, which diameter is quite large (usually a half an inch). Maximum echo appears when equiphase surfaces coincide with the surface of the ball. This definition gives a focal distance much shorter than others.

1.2.2. : a ball or a disk which diameter is small. Those reflectors are usually considered as giving the same result. We observed some little differences that we neglected in this work. The so defined distance is usually called "Acoustic focal distance", F_{ac}.

1.2.3. : a quasi infinite plane normal to the axis of the beam.[3]

2. Comments on those definitions :

Definition by small targets is very simple to link with theory. Maximum echo corresponds with theoretically calculated maximum of acoustic pressure. But it is not very easy to determine practically because precise centering of ball with respect to beam axis is needed.

Definition by plane is not easy to relate with theory. We can only say that this distance is greater than F_{ac} and smaller than F_{opt}. Exact computings are in progress. This focal distance is very easy to measure practically.

3. Diameter and length of the beam.

Although refering to slightly different definitions, authors are nearly in accordance on definition of beam diameter.

Differences appears when defining the length of beam. Some definitions take into account the whole -3dB isobar (limit of -6dB echo), others refer to a truncated part of it.

We looked to compare results given by those definitions of beam length. To do so, the needed apparatus is quite simple; it is schematized on fig (1). Wide-band and narrow-band methods could be used : Targets are ends of cylinders which diameters are 1, 2, 5, 10mm, 60mm (quasi-infinite plane) and 1mm diameter ball.

III. RESULTS :

Measures have been made with many transducers. Results are, for the main part, similar. So we did choose to present the whole results obtained for a probe which characteristics are medium.

D = 15mm, Frequency = 4 MHz

F = 60 or 70mm .....(according to definitions)

g_{ac} = 0,4 bandwidth ⇒ figure 2

1. Attenuation against distance

Mesure of echos sent back by disks (1, 2 and 5mm diameter) and quasi infinite plane normal to axis are plotted against γ in upper parts of figures 3 to 10.

Echo variations are slightly dependent on emission, but notably on target. When target diameter goes small, the position of maximum echo moves towards transducer and variations around this maximum are faster.

Results of calculating the length of the beam are

- according to [2]

$$F_{ac} = 60\text{mm} \qquad \ell_0 = D^2/4\lambda = 150\,\text{mm}$$

$$g_{ac} = F_{ac}/\ell_0 = 0{,}4$$

$$\gamma_1 = \frac{\ell_0}{2}\left(\sqrt{1+4g_{ac}} - 1\right) \simeq 46\,\text{mm} \qquad \gamma_2 = \ell_0\left(g_{ac} + g_{ac}^2\right) \simeq 84\,\text{mm}$$

- according to [3]

$$F = 70\text{mm} \qquad L = 4\lambda\,(F/D)^2 = 32\text{mm}$$

usefull beam between : 54mm and 86mm

With a 2mm possible error on F, variation of calculated beam length is less than 5mm [2] less than 4mm [3] . The most uncertain limit is the far end of beam.

Those calculated lengths are plotted on middle parts of fig. 3 to 10.

2. Attenuation against inclination.

We have determined what was target rotation giving a 6dB attenuation, as a function of emissions, targets, and distances in the vicinity of theoretical beam. Results are plotted on lower parts of fig. 3 to 10.

The indicated value is the mean of $+\alpha$ and $-\alpha$. One curve "absolute" (plotted : o) is obtained taking as a reference maximum echo. The other "relative" (plotted : +) takes as a reference the echo of normal target at the current distance . Curves are cut when measures cannot be reproduced and for $\gamma > 115$mm.

Comments :

- Relative curves are approximately constant for large γ variations
- For limited γ variation "relative" and "absolute" curves join together.
- Often, for large targets, when γ is small, echo is smaller when the disk is normal to axis than when disk is inclined.

That could be explained. Theoretical work let appear curvature of equiphase surfaces,and maximums of pressure out of axis. According to "stationary phase principle", a large echo can appear where equiphase surface is tangent on target plane . On fig. 11 one can predict a slight attenuation from position A to position B of target, and lower echo on C than D .

CONCLUSION

Method is criticable. Targets are not exactly similar to defects in materials. That is only a usefull step in a more complicated work.

Keeping target center on axis we eliminate the diffraction by tip phenomenon [4],[5] .

Such an arrangement have been choosen to let our results be comparable to previously published ones [1] .

Definition of focal distance should mention what is the used target. This definition is influent on beam length.

Rotation of target for 6dB attenuation is not anomalous, but on the nearest part of the beam.

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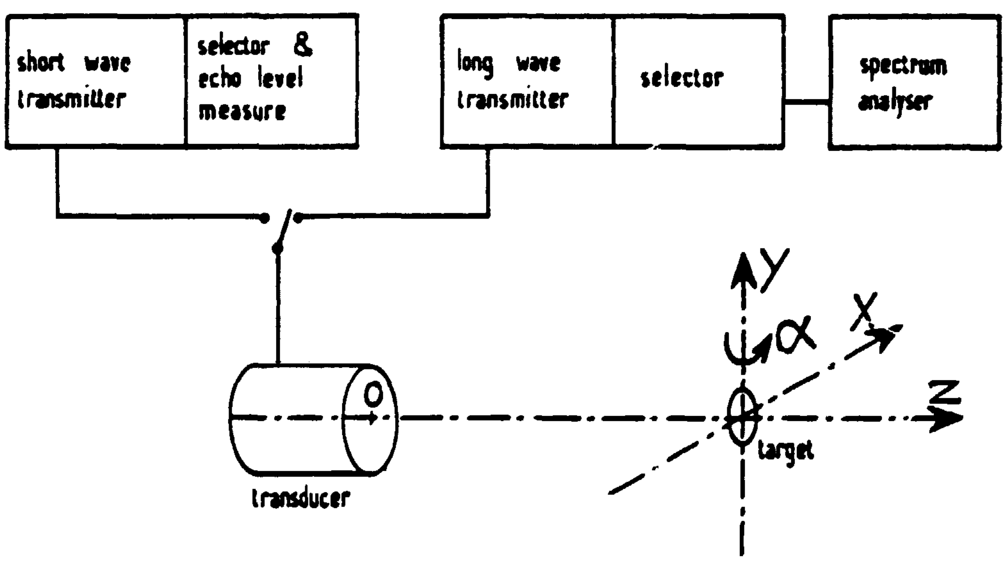


Figure 1: Diagram of experimental equipment.

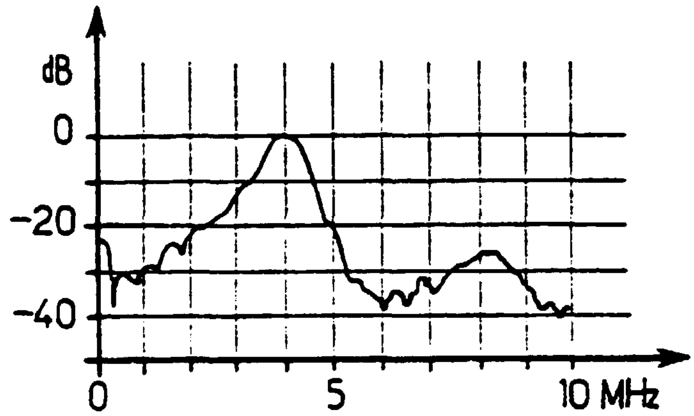


Figure 2: Frequency spectrum.

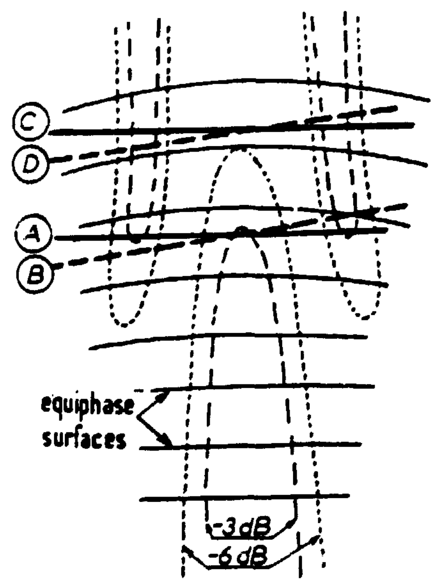
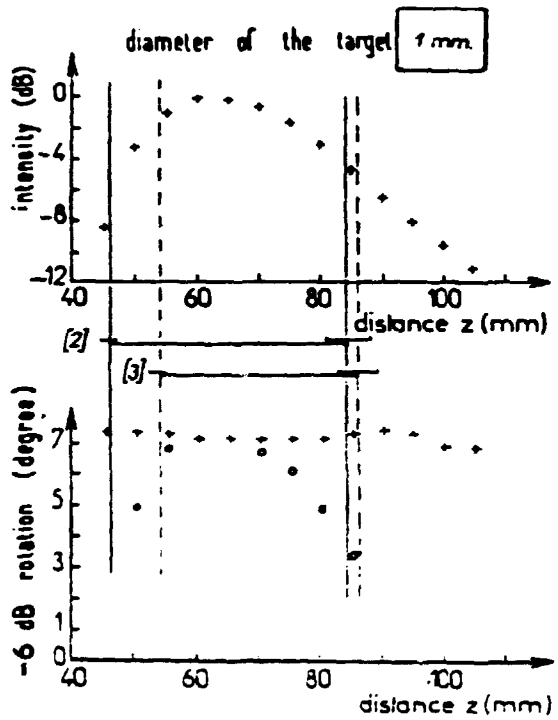
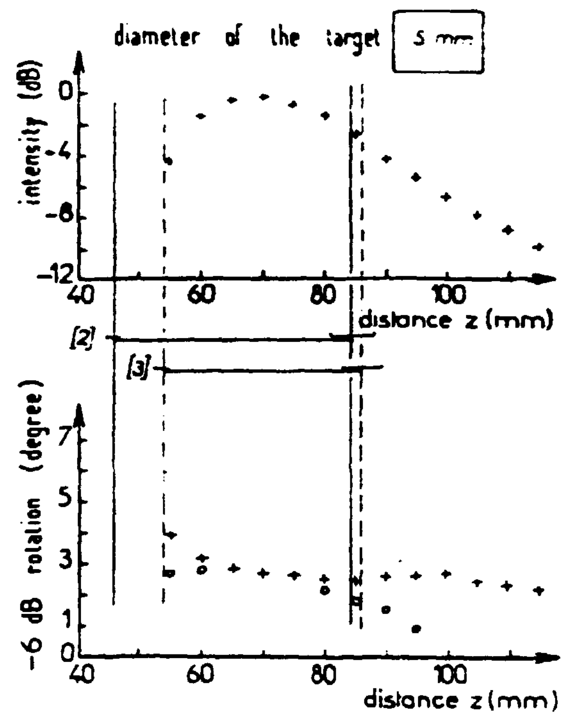
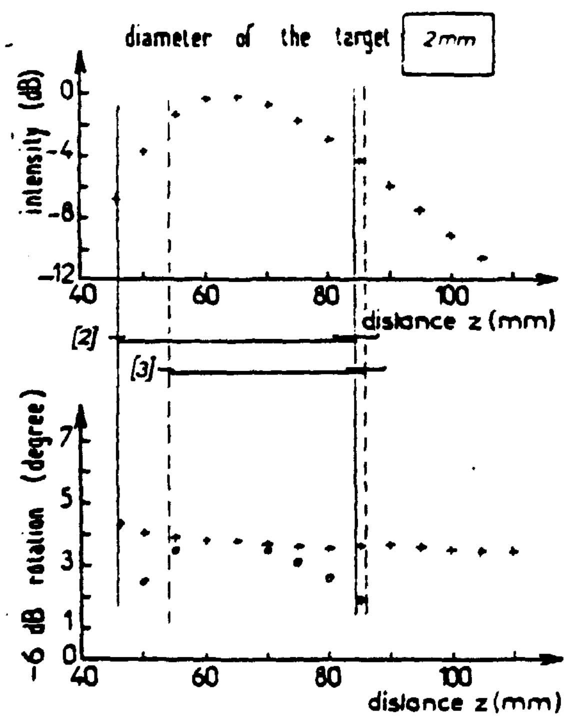
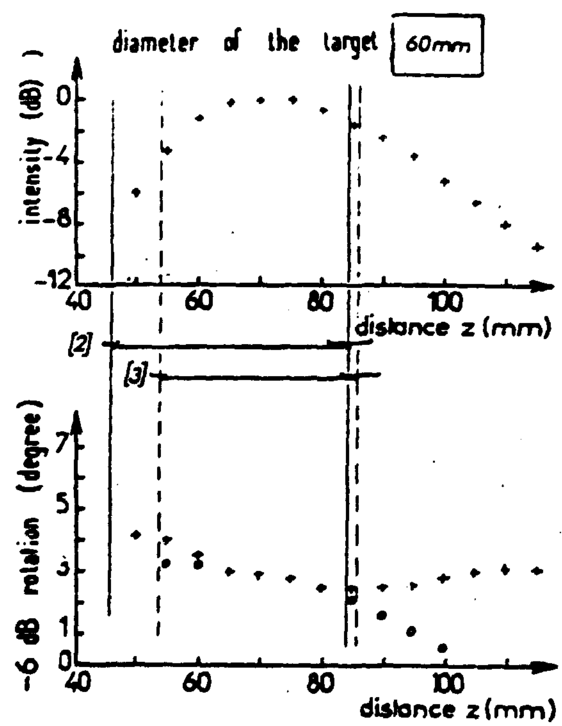


Figure 11: Isobars and equiphase surfaces in the vicinity of the front part of beam.(simplified diagram).

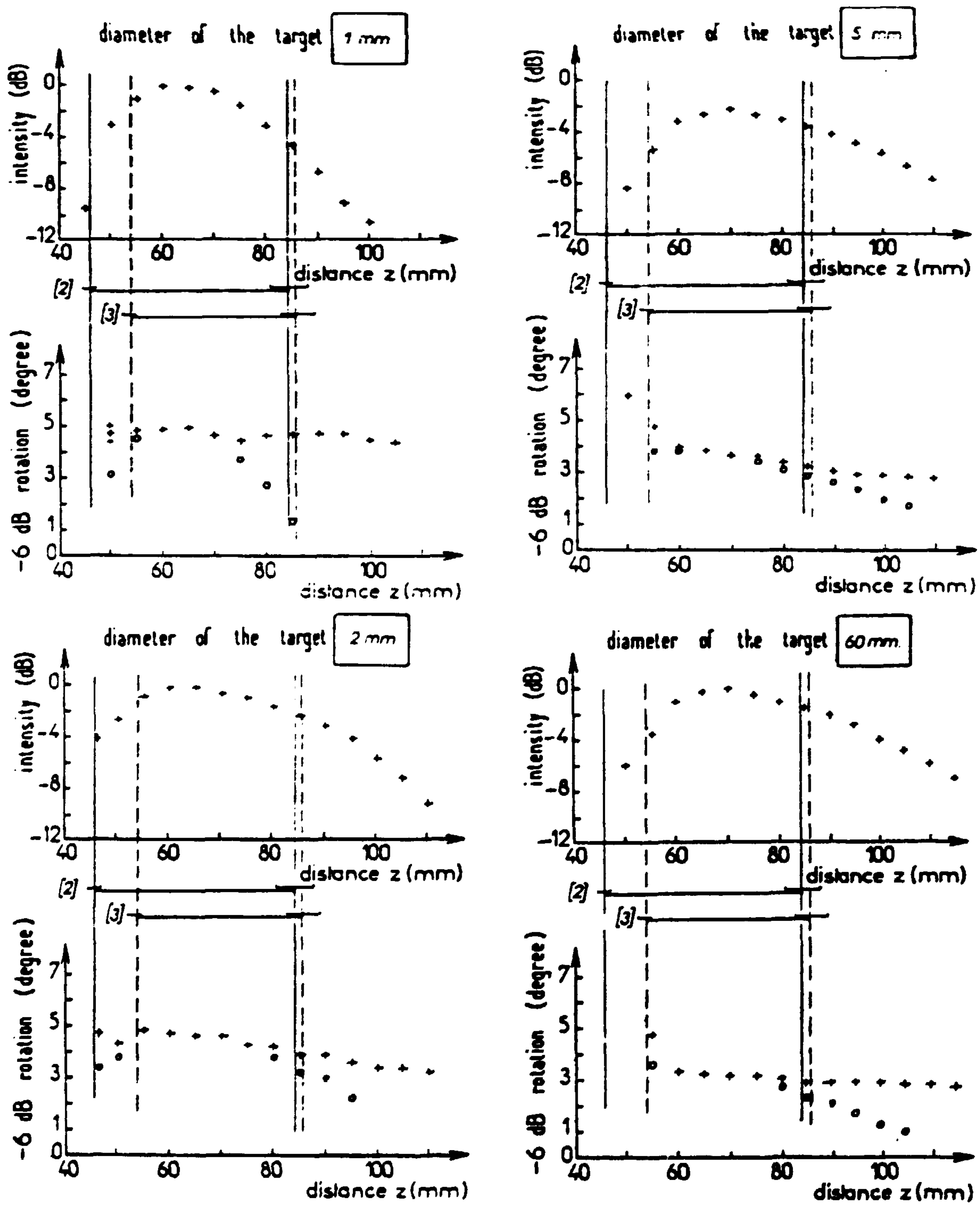








Figures 3|5 / 4|6 : Narrow-band results.



Figures 7|9 / 8|10 : Wide-band results.