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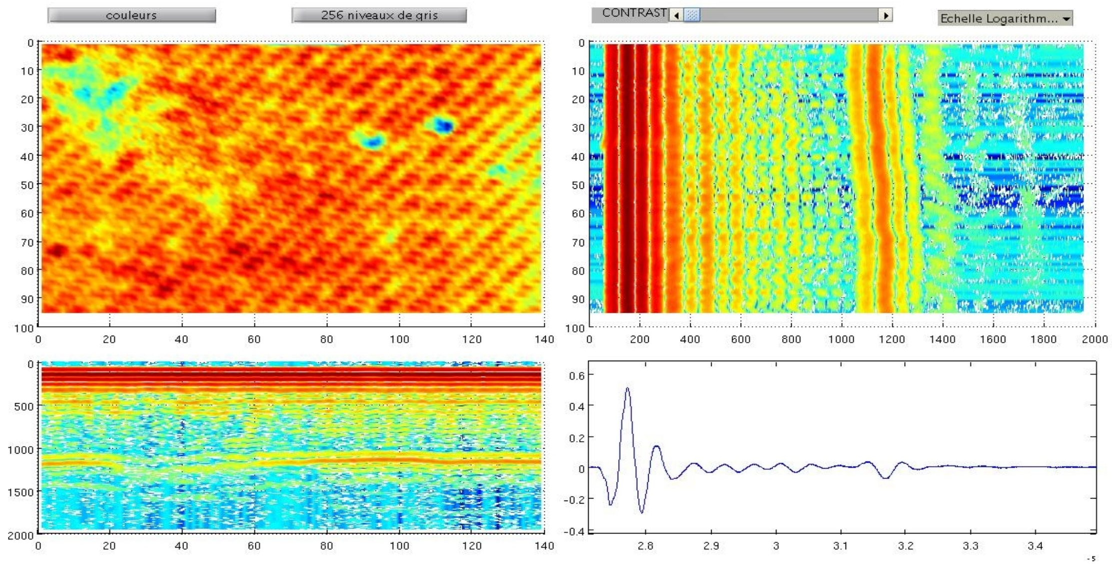
4SGM
Non-Destructive Testing
Ultrasonic Testing



Philippe GUY

philippe.guy@insa-lyon.fr

LVA - INSA de Lyon

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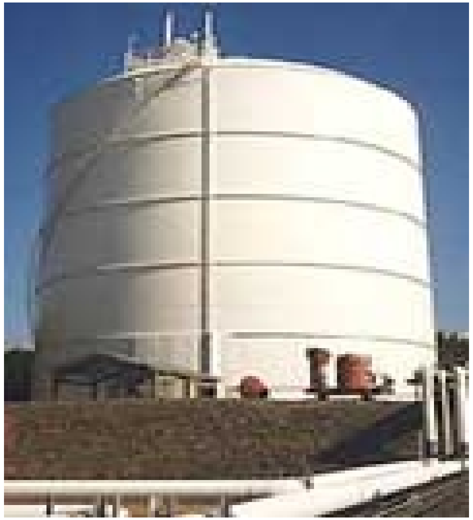
Ultrasound industrial applications – some examples


Rails

Bridges


Storage tanks


Pipelines

Ship hulls


Aircraft structures


Pressure vessels

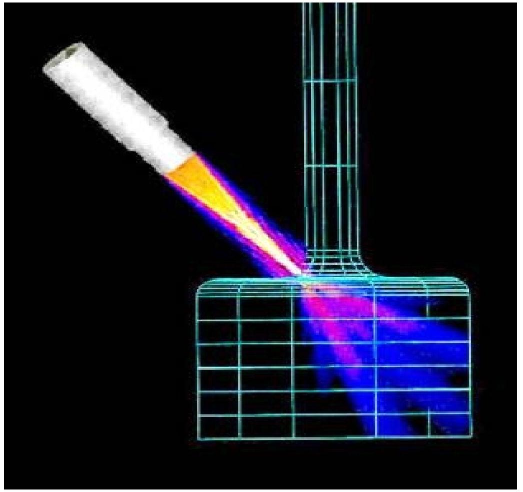
Basic principles of Ultrasonic Testing

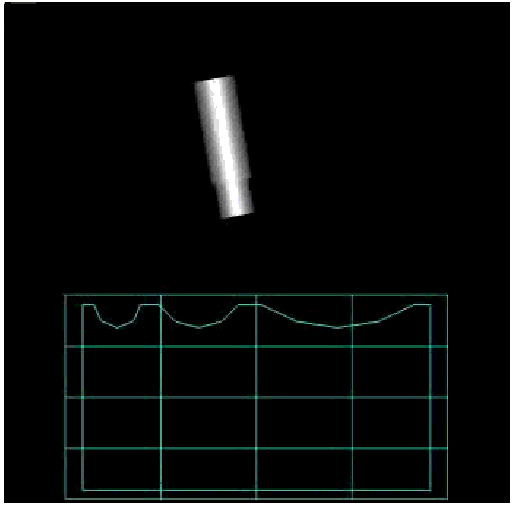
Ultrasonic waves are introduced into a material where they travel in a **straight line** and at a **constant speed** until they encounter a surface.

At surface interfaces some of the wave energy is reflected and some is transmitted.

The **amount of reflected or transmitted energy** can be detected and provides information about the size of the reflector.

The **travel time** of the sound can be measured and this provides information on the distance that the sound has traveled.





Video illustration

Advantages of UT Methods

- Bulk method : the **penetration** of ultrasounds allows to inspect the materials on **important depths**
- Method requiring **access** to the part from **only one side**
- **Speed** and **simplicity** of implementation;
- No chemical or radiological disadvantages;
- High sensitivity over a **wide range of defect** and **part dimensions**
- Quantitative diagnostics and evaluation of the method's performance, thanks to numerous modeling tools
- **Adaptability** of the methods to the **materials** and **geometries** of the parts. Applicability to most **materials, metallic or composite** ;
- Richness of the information provided: Possibility to precisely **locate** defects, to **dimension** defects and to **image** the inspected region ;
- Availability of phases-array techniques that multiply the performance of conventional ultrasound;
- ultrasound is the subject of active R&D and **continuous technological innovation**.

What are UT Methods used for ?

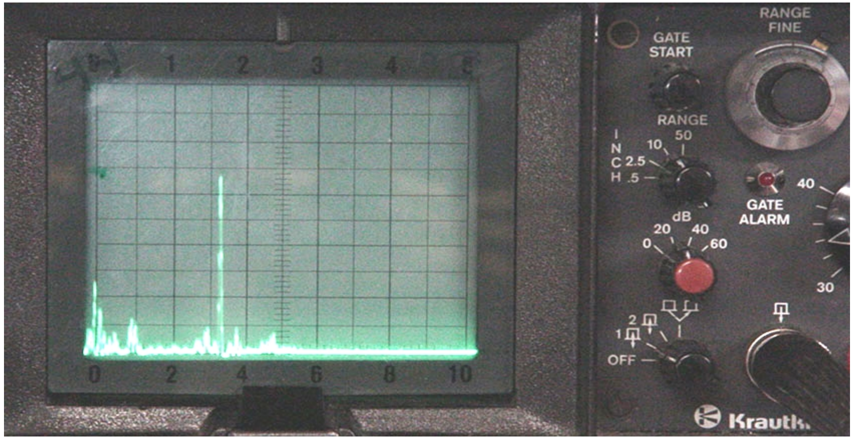
- Crack detection and Evaluation
- Welds inspection
- Composite inspection
- Porosity detection and evaluation
- Flaw depth evaluation
- Flaw identification (bulk or flat)
- Thickness gauging
- Structure and Microstructure Characterization
- Evaluation of Mechanical and Physical Properties
- Stress (Strain) Measurements
- Material Sorting (steel grades)

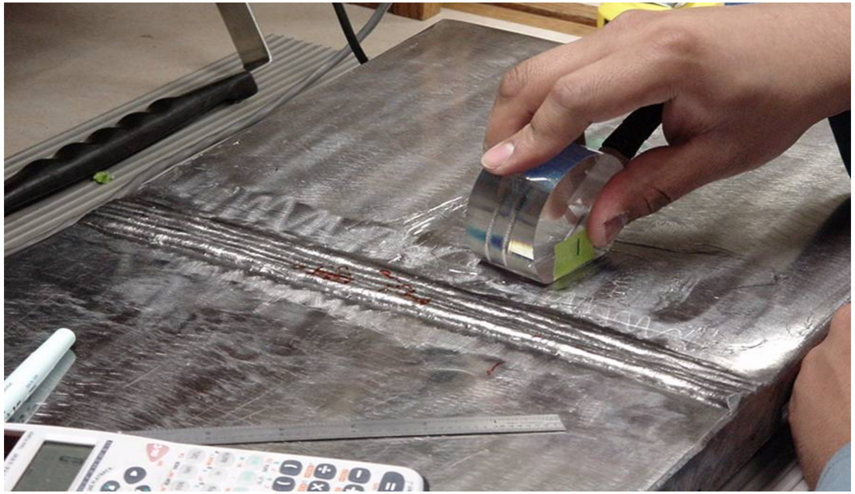
Fluorescent penetrant indication

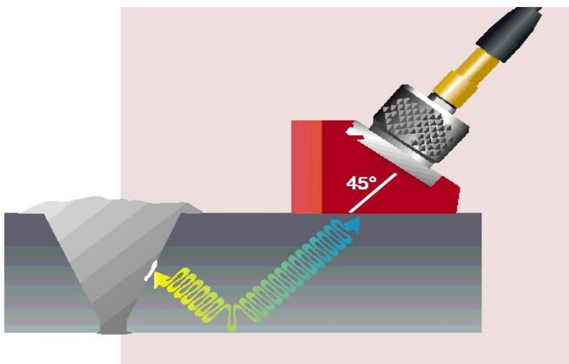
Flaw Detection in Welds

One of the most widely used methods of inspecting weldments is ultrasonic inspection.

Full penetration groove welds lend themselves readily to angle beam shear wave examination.





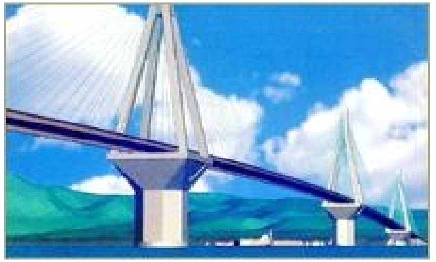


When are UT Methods Used?

There are UT applications at almost any stage in the production or life cycle of a component.

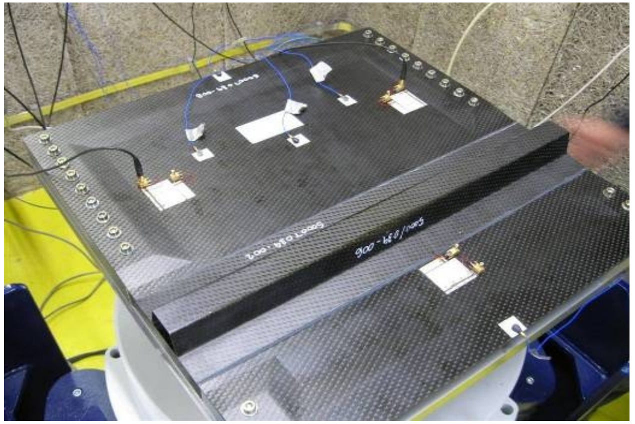
- To assist in product development (process validation)
- To screen or sort incoming materials (steel grades for instance, texture analysis ...)
- To monitor, improve or control manufacturing processes
- To verify proper processing such as heat treating
- To verify proper assembly (welds, bonds, bolts ...)
- To inspect for in-service damage

- **Today developments in UT**



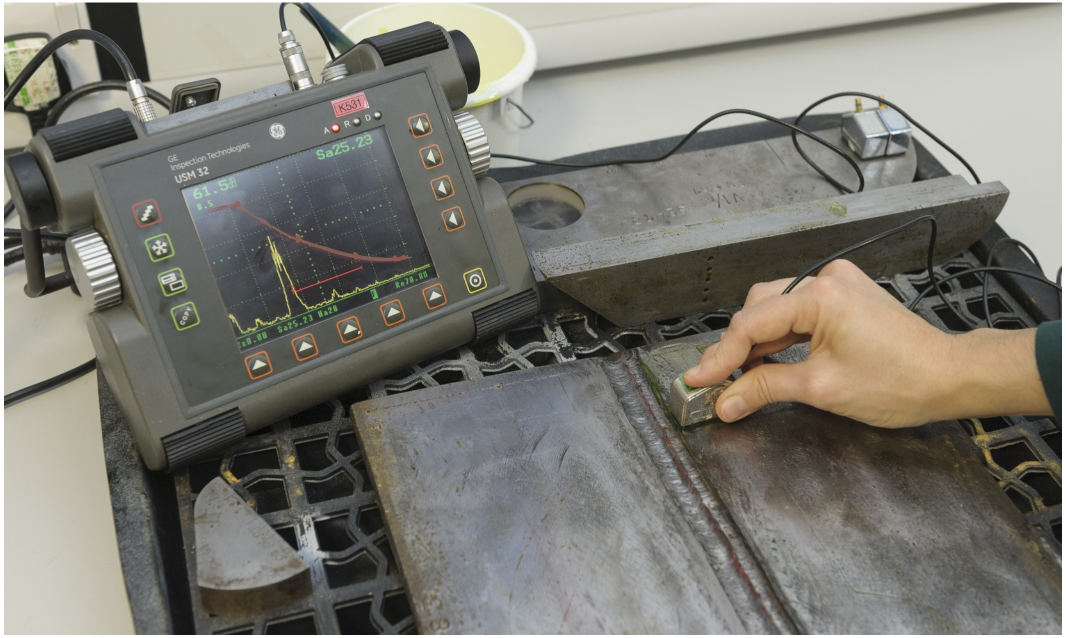
- Automation
- Phased arrays
- Long range UT (guided waves)
- Time of Flight Diffraction Technique (TOFD : mainly for welds inspection)
- Dry coupled UT

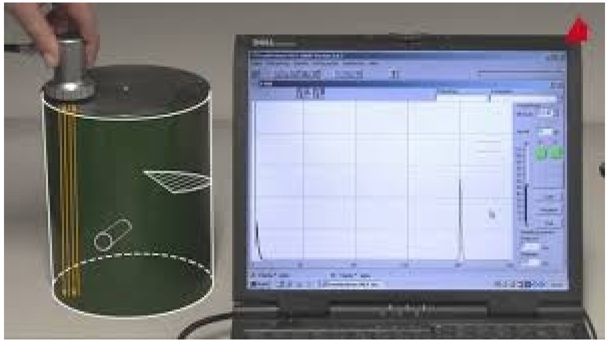
  Sensor integration (Structural Health Monitoring)
- Data fusion
- Full Matrix Capture -Total Focusing Method (FMC – TFM)
- SIMULATION
  - Fabrication process optimization
  - Training of inspectors



- Searching for alien bodies (inclusions, pollutions, etc...)
- Highlighting heterogeneities of physical properties (microstructure, texture, rugosity etc...)

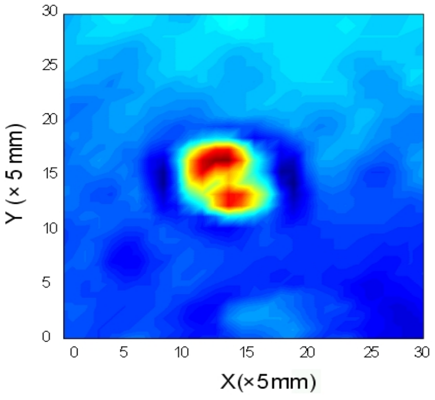
Some practical situations



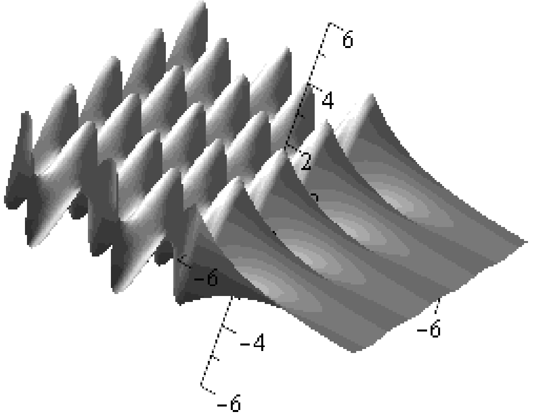


Objectives of this course

- **Introduce some examples of applications in NDT**



- **Introduce the fundamental concepts of elastic waves propagation**



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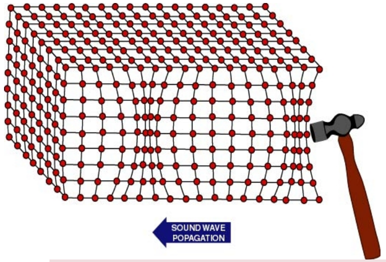
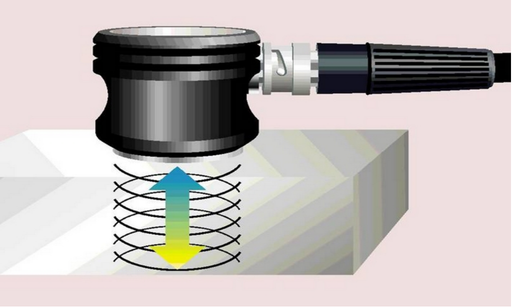
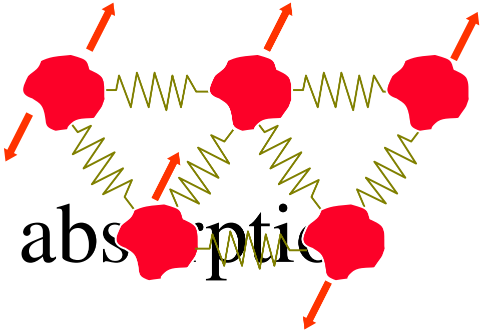
Wave propagation requirements

- Introduction of a disturbance
  - a **source** inputs energy
  - rupture of equilibrium conditions





- Coupling mechanism

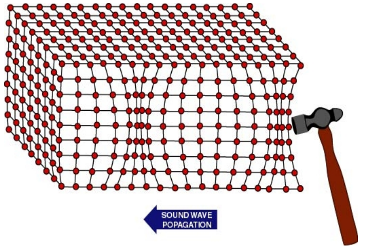


- Weak absorption

The source

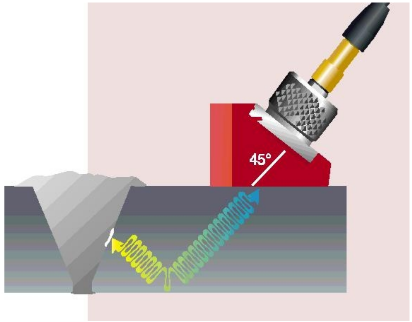
- Definition
  - External agent that introduces a local disturbance of the equilibrium state of the propagating medium

    (in contact or not)



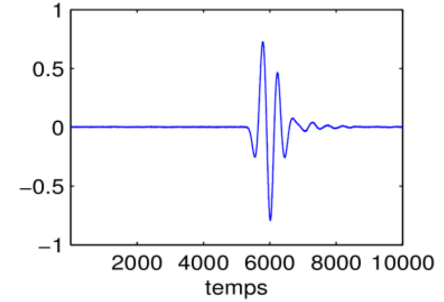
  - The source inputs energy into the media

  - Transducer that converts electrical into mechanical power

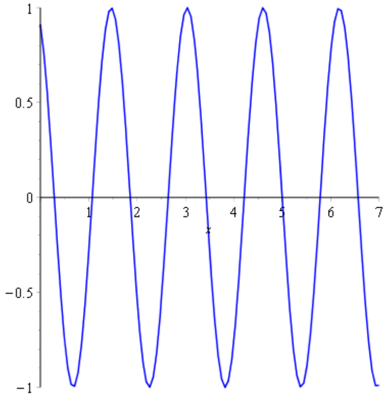


Excitation modes of the source

- Excitation modes of the source
  - Pulsed mode
    - the source is activated during a short duration
    - the usual way in NDT



  - Continuous mode
    - the source is activated permanently.
    - important particular case : harmonic excitation
    - convenient for analytic models
    - for resonance methods



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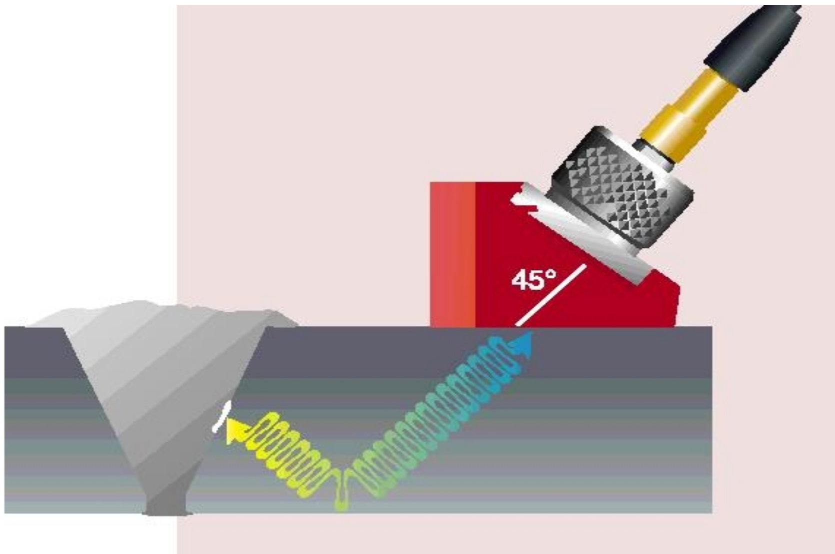
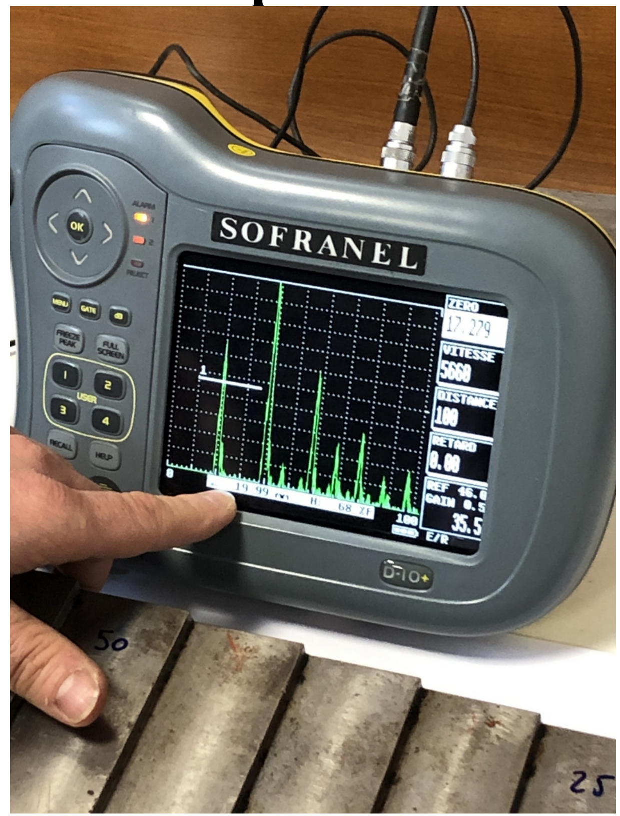
How to produce Ultrasound ? Collect and represent the data.





Philippe GUY

philippe.guy@insa-lyon.fr

LVA - INSA de Lyon

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Some of the illustrations are from : INSAVALOR

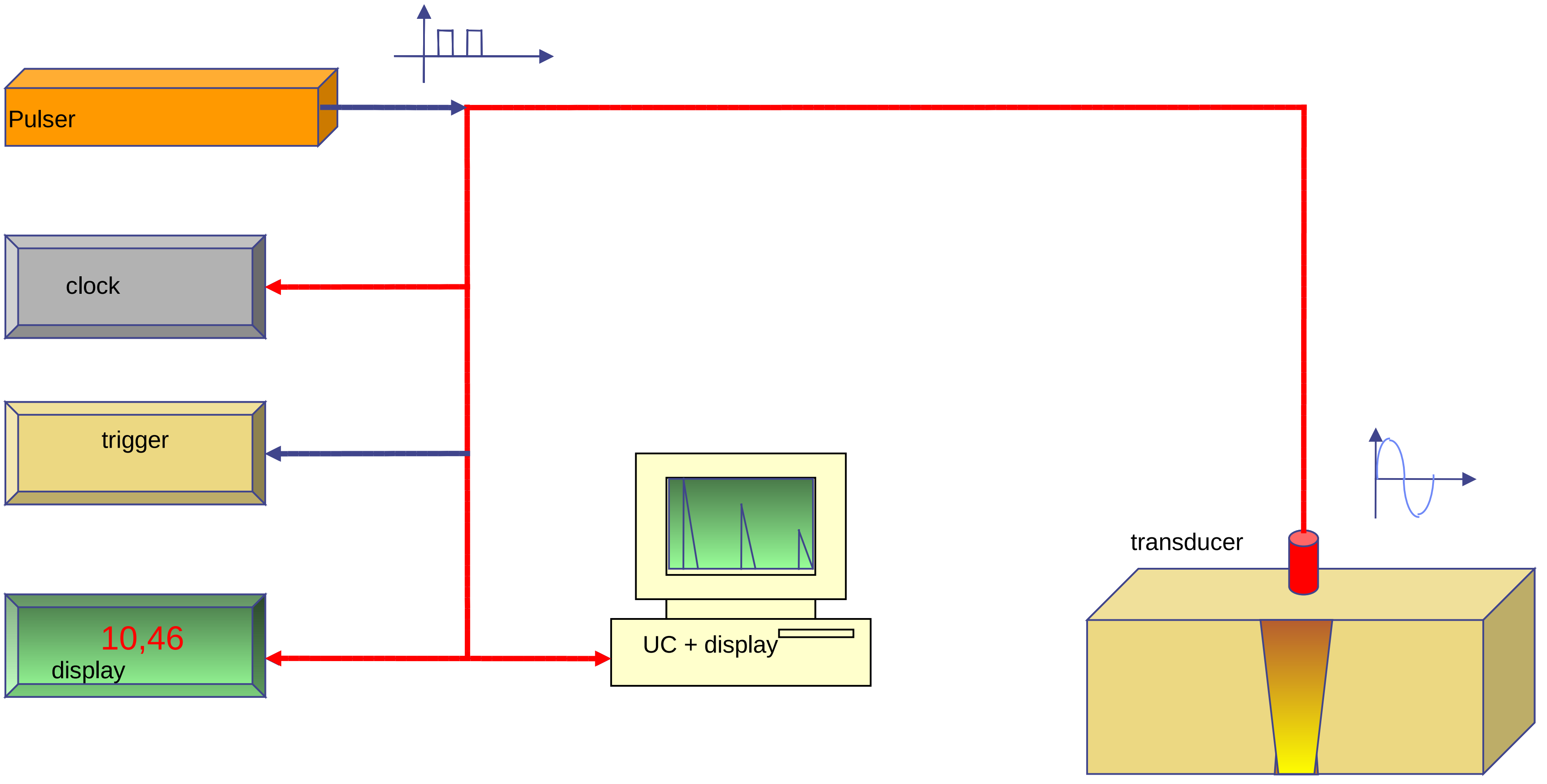
Characteristics of a typical ultrasonic device

In any ultrasonic device you will find :

- ***an emitter :*** *circuit that produces and amplifies the electrical pulse*
- ***a receiver :*** *circuit that amplifies the received electric echoes on a receiving tranducer.*
- ***a time base :*** *circuit (or memory) that sweeps the screen with a variable time scale.*
- ***a display*** *(can be your computer or laptop)* **:** *allows the visualization of the collected signals*

http://www.sofranel.com/fr/prisma-015

Schematic of an ultrasonic device



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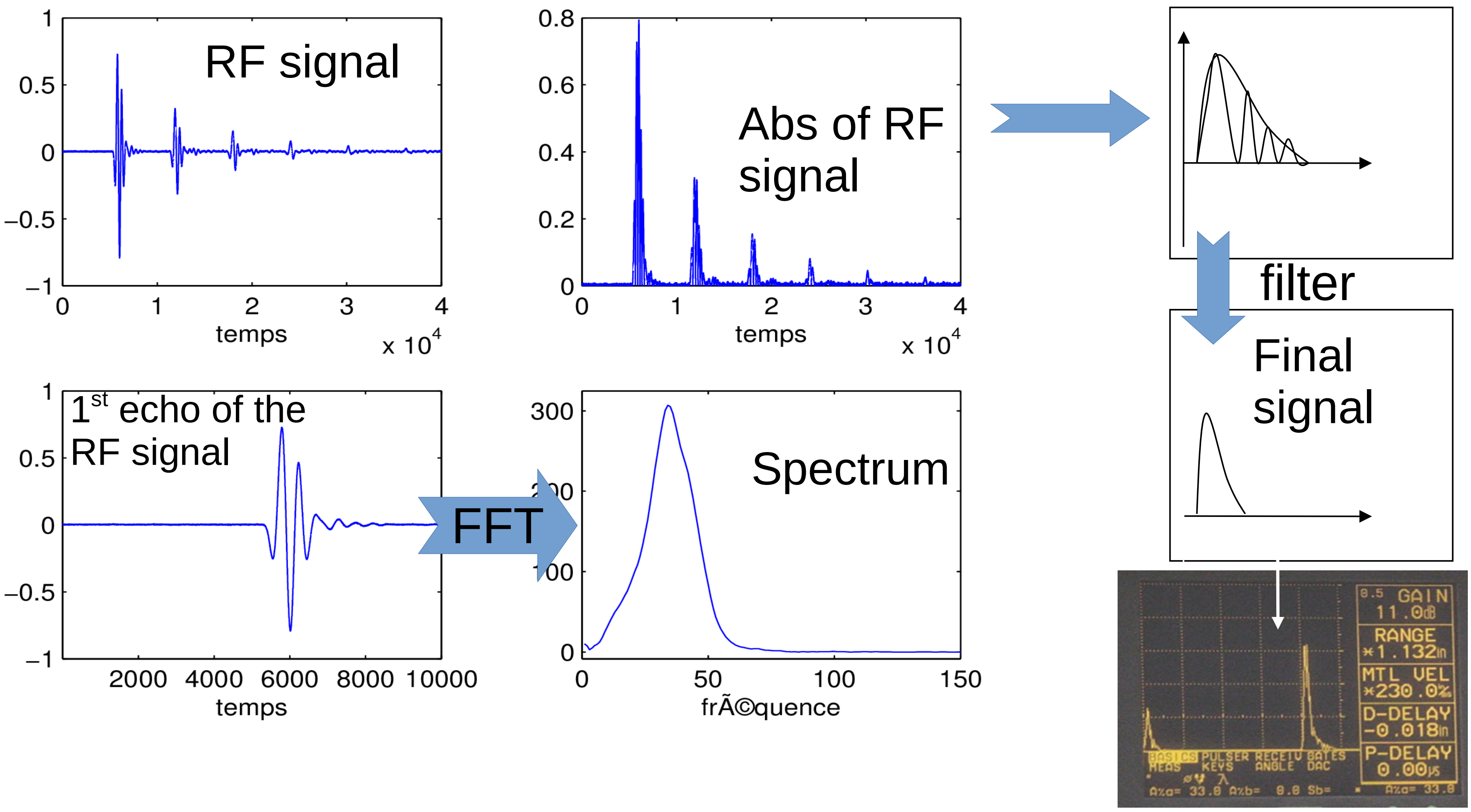
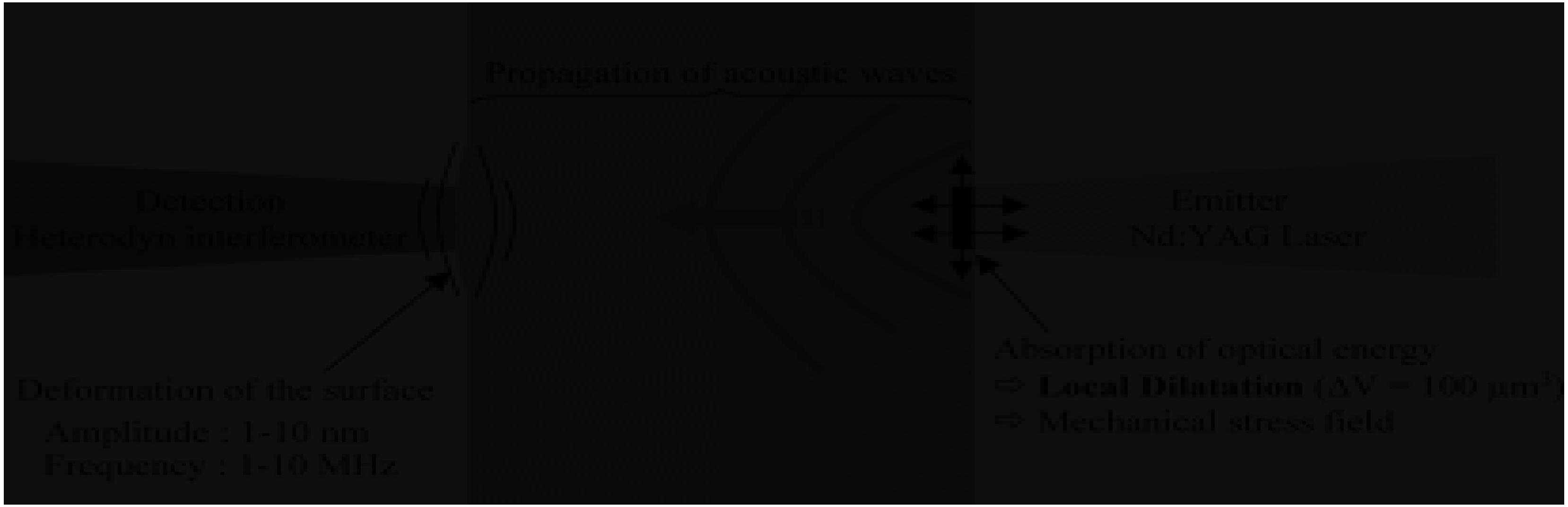
Conditionning of the signal.



How to produce ultrasound ?

Non contact techniques (1) : Laser-Ultrasonics

Thermoacoustique conversion



A high power laser flashes sur surface of a material.

=> very rapid local elevation of the temperature.

=> rapid thermal expansion => production of ultrasound

Advantage : Non contact and reproducible production and detection of ultrasound
Drawback : Possible ablation regime !! (No more non destructive)

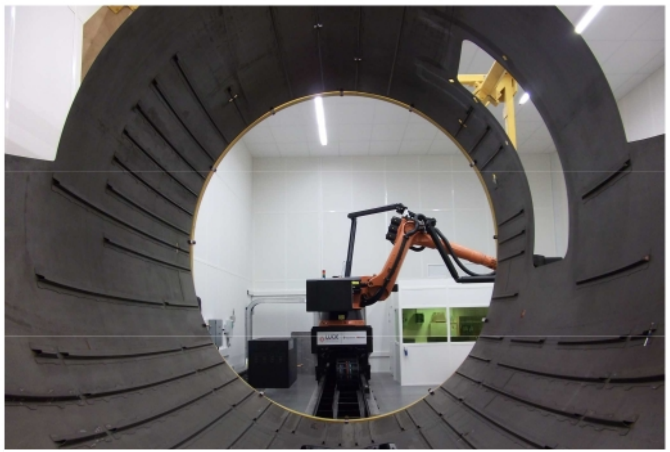
Non contact techniques (1) : Laser-Ultrasonics

Example : LUCIE robot (EADS)

Nose Fuselage Demonstrator

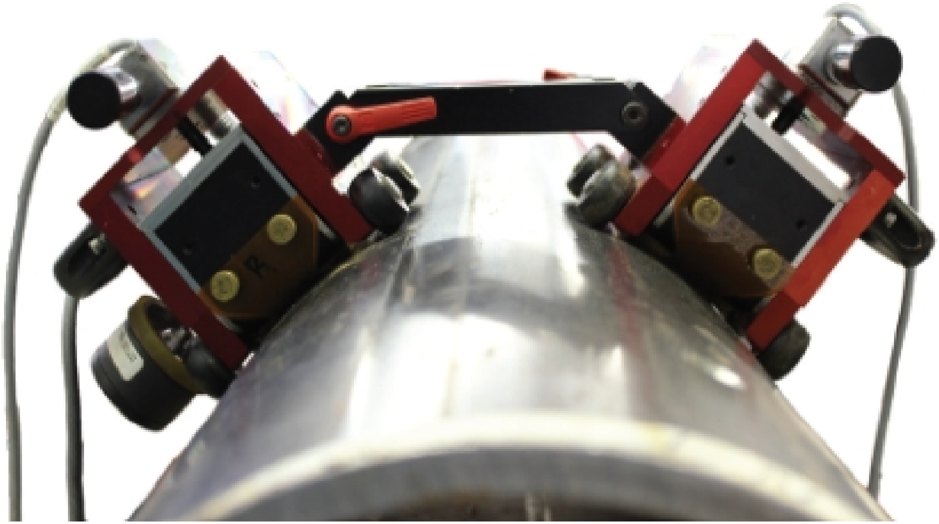
System sized for NoFudem inspection

- Room size: 16m x 10m x 6m



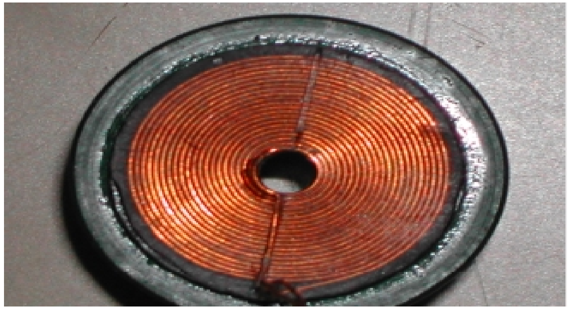
UT Laser dans l'aéronautique Journée Technique CND sans contact – PRECEND -2013/05/16

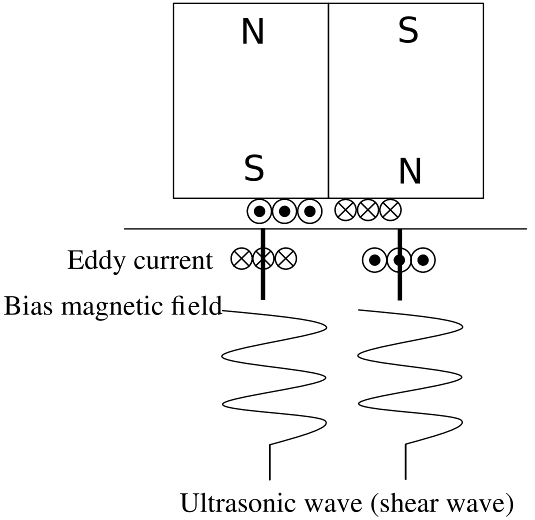
Electro-Magnetic Acoustic Transducers
EMATs



Non contact techniques (2) : Electro Magnetic Acoustic Transducers (EMATs)

Un coil driven by a variable current produces eddy currents into an electrically conducting material.
As a static magnetic field is also applied, the eddy currents distribution will experienced a Lorentz force, and will oscillate => mouvement => ultrasonic wave (L, S, SH, Rayleigh, Lamb, according to the design of the coil and the applied static field)

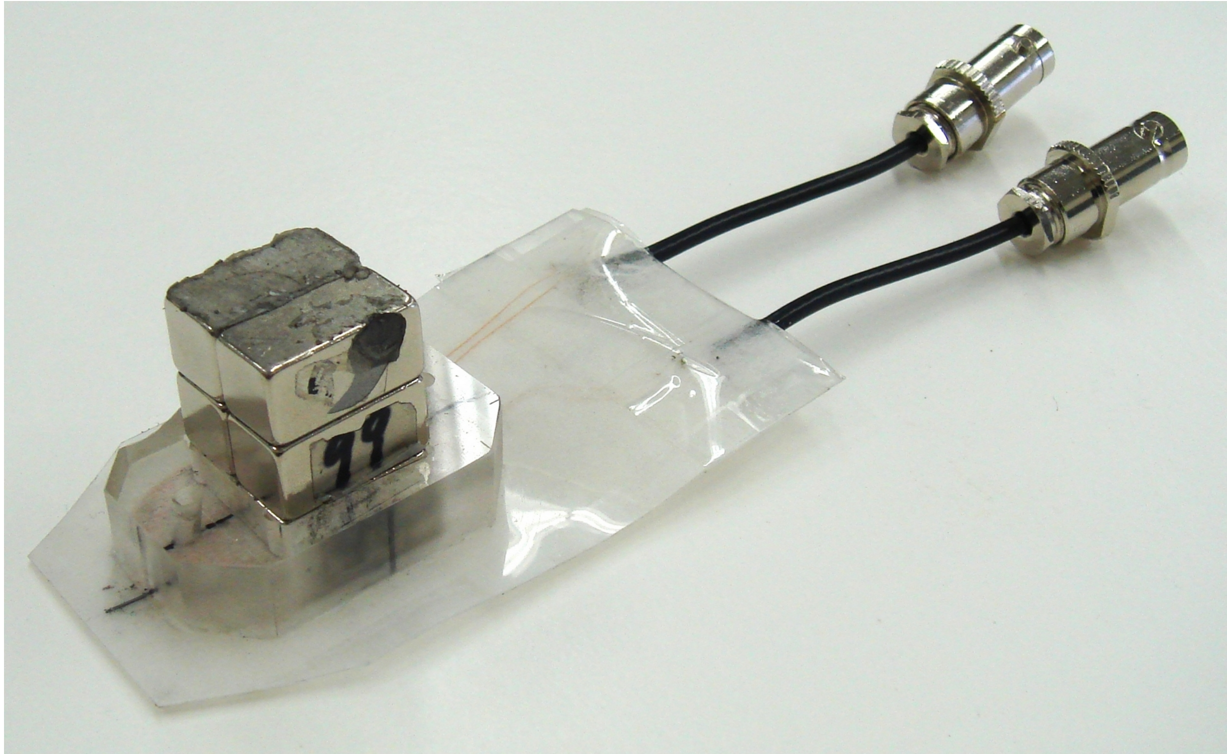




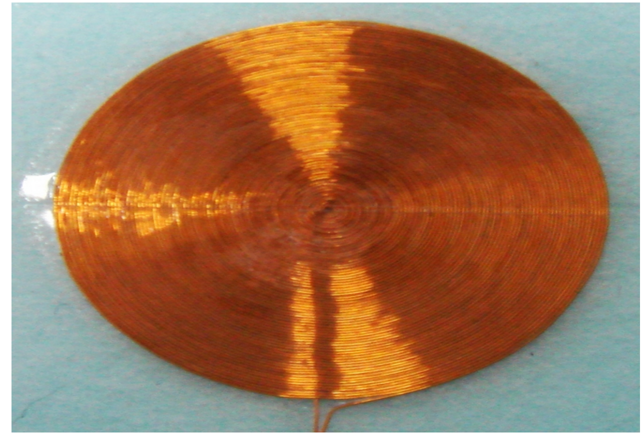
Advantage : non contact excitation
drawbacks : only works on electrically conducting materials

Common application : texture analysis of steel in output of laminors

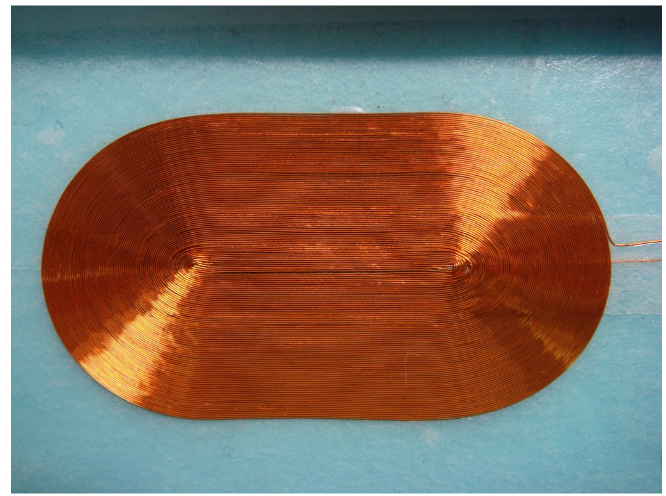
Example of an EMAT-EC Dual Probe



Dual proble



Emitting coil



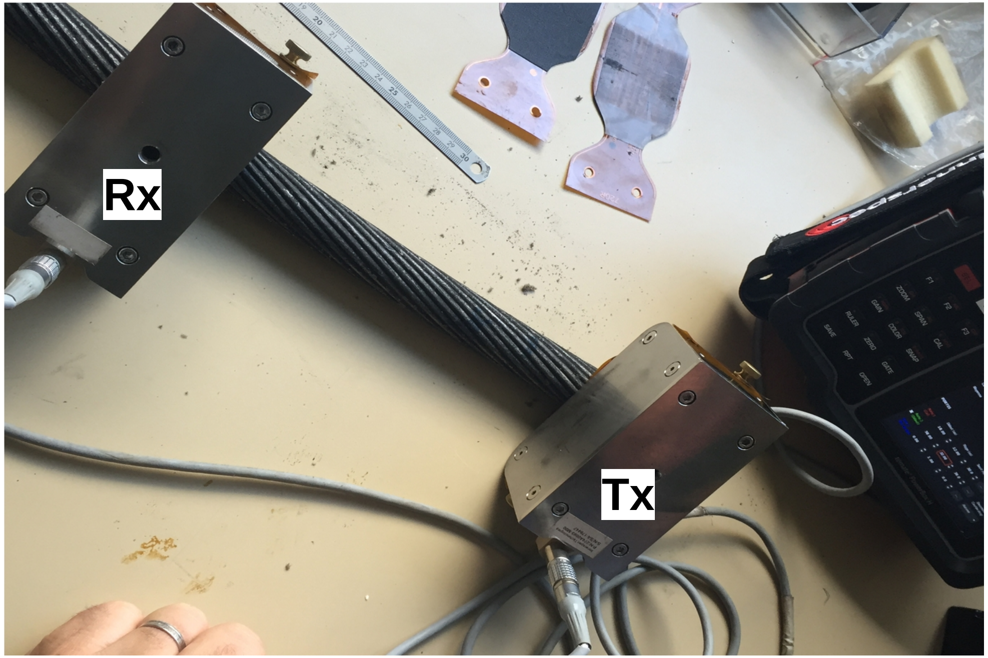
Receiving coil

T. Uchimoto, P. Guy, T. Takagi, J. Courbon, Evaluation of an EMAT–EC dual probe in sizing extent of wall thinning, NDT & E International. 62 (2014) 160–166. doi:10.1016/j.ndteint.2013.12.007.

Exemple de mise en oeuvre

Meander coils
F = 0.5 MHz, λ = 10 mm

Undammaged case



1 : direct transmission between Tx and Rx
2 : reflected wave at the end of the cable

Production of ultrasound with piezoelectric transducers.

Piezoelectricity is the electric charge that accumulates in certain solid materials (such as crystals, certain ceramics, and biological matter such as bone, DNA and various proteins) in response to applied mechanical stress. The word piezoelectricity means electricity resulting from pressure. It is derived from the Greek piezo or piezein (πιέζειν), which means to squeeze or press, and electric or electron (ήλεκτρον), which means amber, an ancient source of electric charge. Piezoelectricity was discovered in 1880 by French physicists Jacques and Pierre Curie. (Wikipedia – english page https://en.wikipedia.org/wiki/Piezoelectricity)

Piezoelectricity is a reversible phenomenon, of linear interaction between the mechanical and the electrical state in crystalline materials.

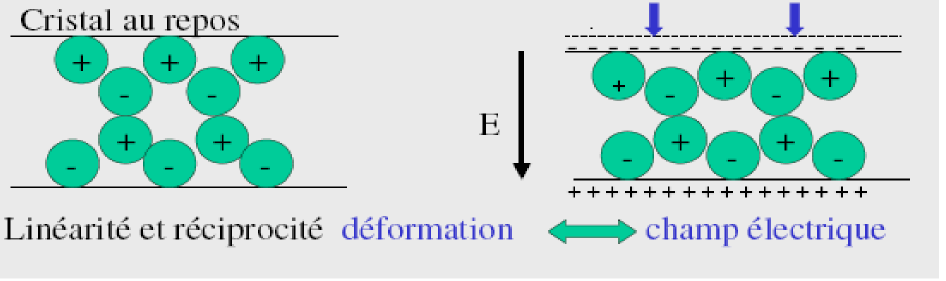
- Piezolectricity has many more application than ultrasound production :
  - High voltage and power sources
  - Sensors, actuators, Piezoelectric motors
  - Frequency standard
  - Reduction of vibrations and noise
  - Dentistry -surgery (thanks to micro-vibrations)

Production of ultrasound with piezoelectric transducers.

Direct piezoelectric effect

Materials for which an electric charge appears (Polarisation) under an applied load (stress σ)

$P = d\,\sigma$ d : piezoelectric tensor



Converse piezoelectric effect

The application of an electrical field E creates a mechanical strain ε of the crystal

Problem : $\varepsilon = d\,E$ ⟶ $\vec{E}$ expansion

$-\vec{E}$ expansion

Solution : Permanent polarisation of the ceramic at $T>T_{curie}$ under V=2000V/mm

$\vec{E}$ expansion

$-\vec{E}$ contraction

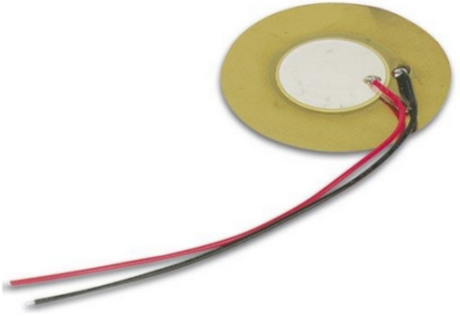
Piezo materials used for the ultrasonic transducers

monocrystals : quartz for instance

Piezoelectric polymers : PVDF (easier for complex shapes but bad coupling factor)

Ferroelectric ceramics (easy to manufacture through the powder mettalurgy)

- ex :   PZT = Pb(ZrTi)O_3 (Lead Zirconate Titanate) the most used for UT transducers



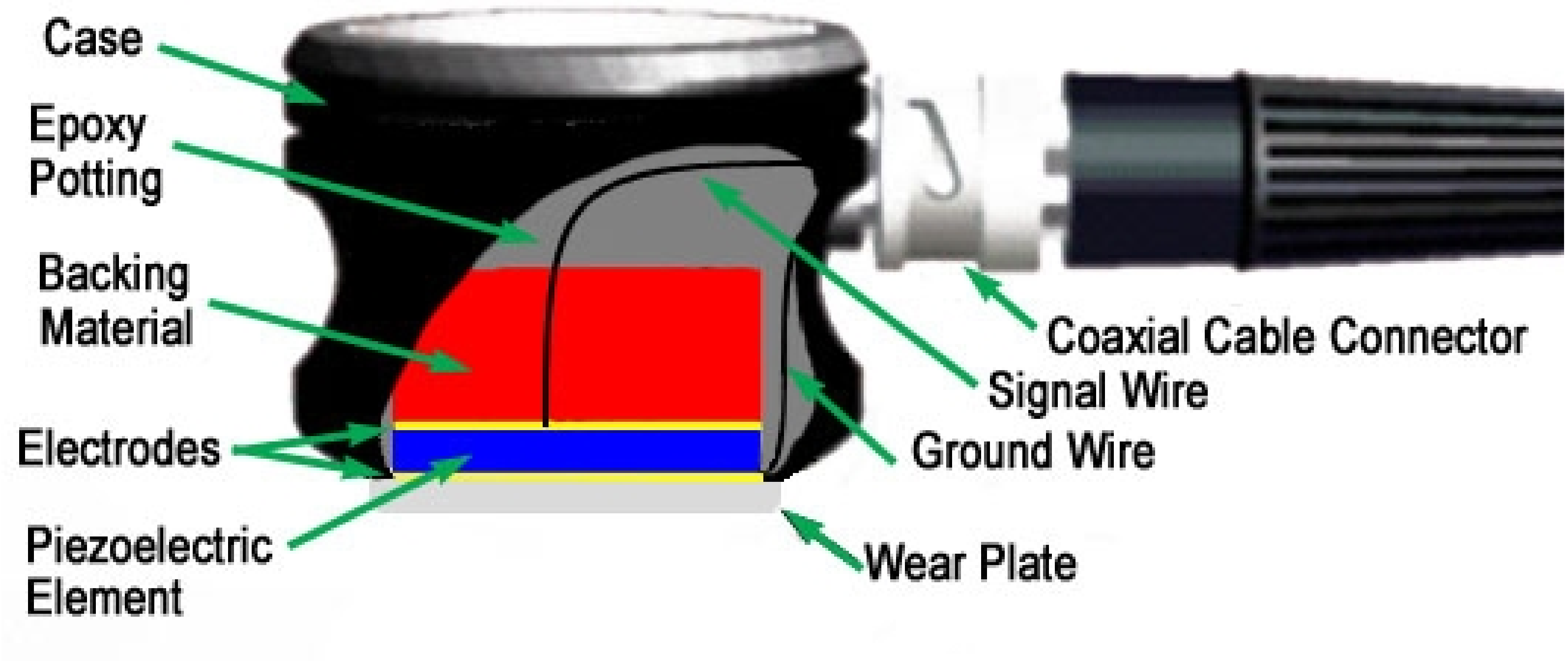
Physical characteristics of some piezolectric materials

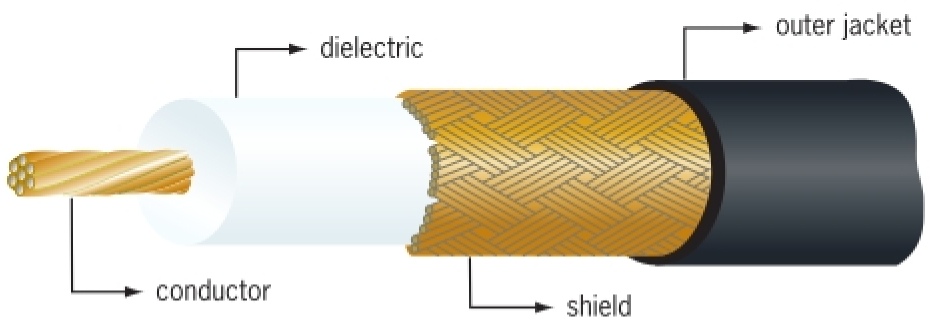
Matériaux	Curie T° ° C	V_L m/s	Impedance $Kg{,}m^{-2}{\cdot}s^{-1}$ (Ray)
Quartz	575	5750	15,2
Lithium Sulfate	75 Désintégration	5450	11,2
Tourmaline	870	7180	22
Lithium Niobate	1210	7300	34
barium Titanate	120	4460	24
PZT	**300**	**3800/4000**	**28 - 30**
Lead Metaniobate	570	3300	20

The main available commercial transducer are piezoelectrics

www.olympus-ims.com

What constitutes a piezoelectric transducer ? (normal beam case)





Coaxial cable

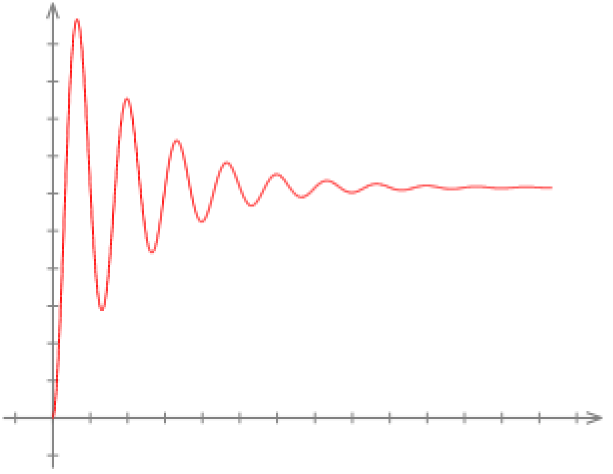
Role of the backing

When submitted to an electric pulse, the piezoelectric element starts vibrating. Ultrasonic longitudinal waves travel back and forth through its thickness.

After each round trip, a fraction of the ultrasonic beam crosses the forward face and enters the material.

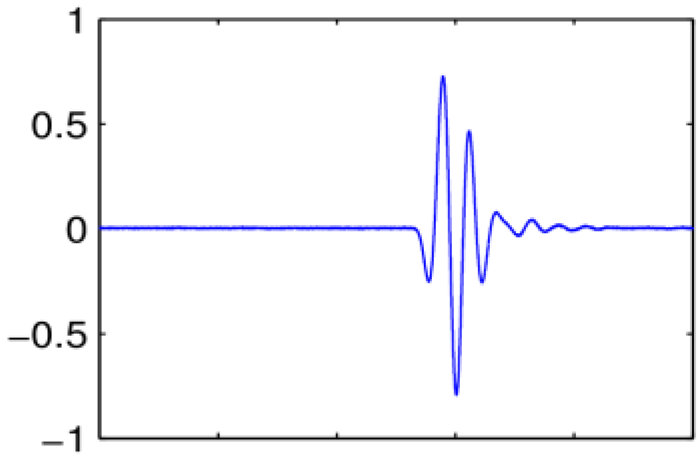
If there is no backing, the duration of the resonnant signal can be quite long and hence its frequency content is very narrow around the resonnance frequency of the piezoelectric element.

(Problems of resolution, small bandwidth).

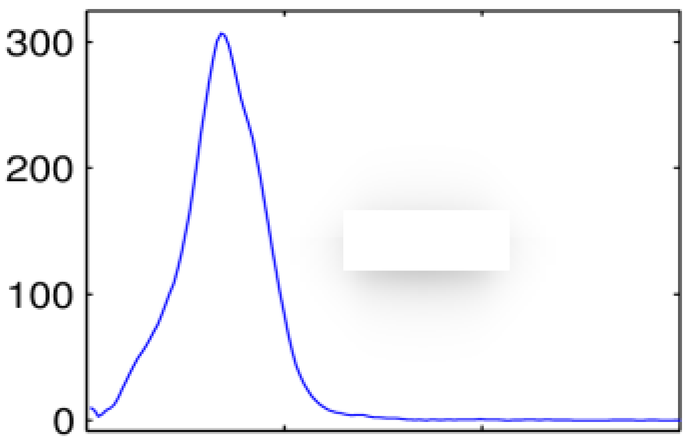


Role of the backing (2)

With a backing, the resonances of the piezoelctric element are damped so that, the duration of the emerging pulses is reduced and the bandwidth is enlarged. The maximum of the frequency spectrum remains centered at the resonance frequency of the piezoelectric patch, but the amplitude of vibration has decreased..

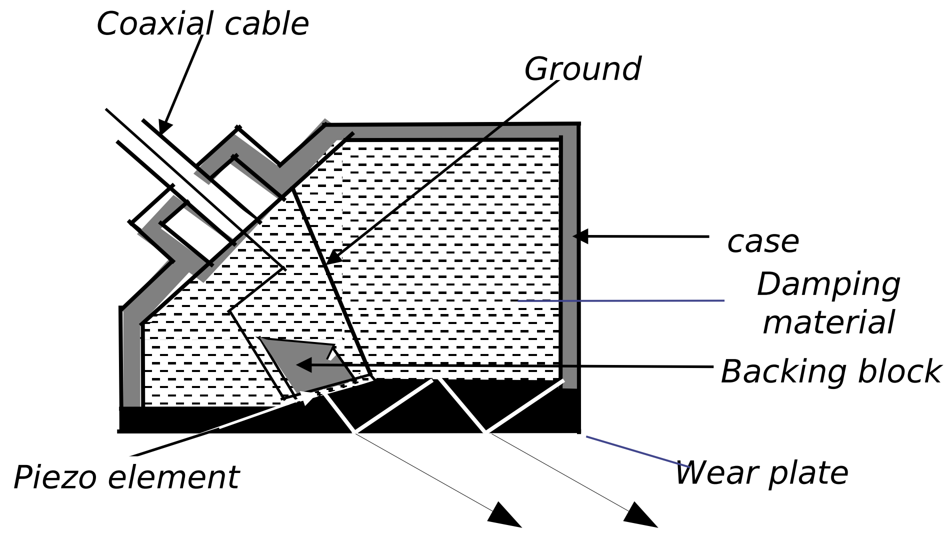


time

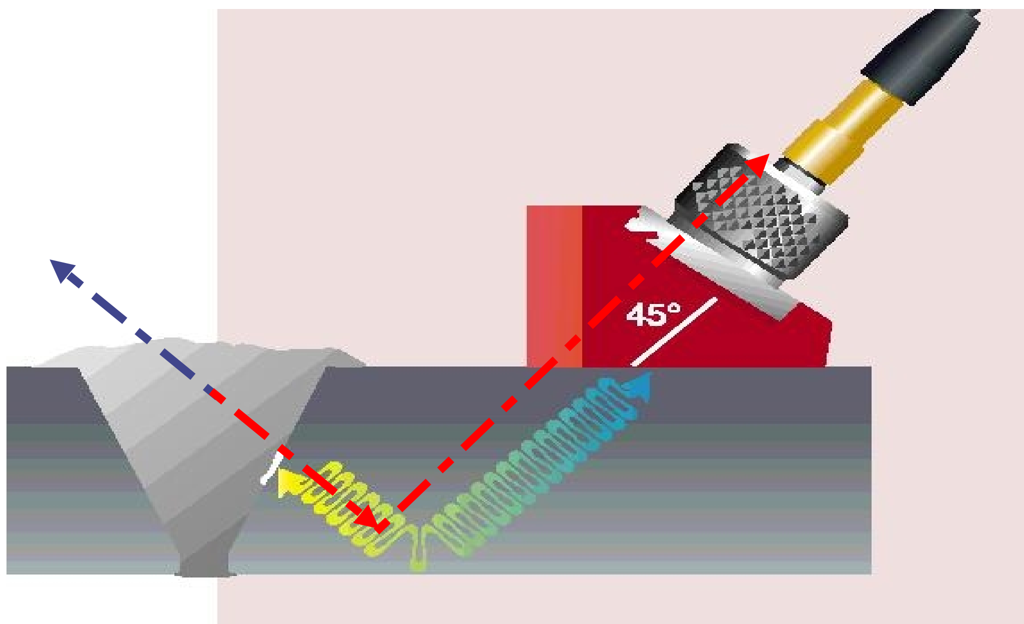


frequency

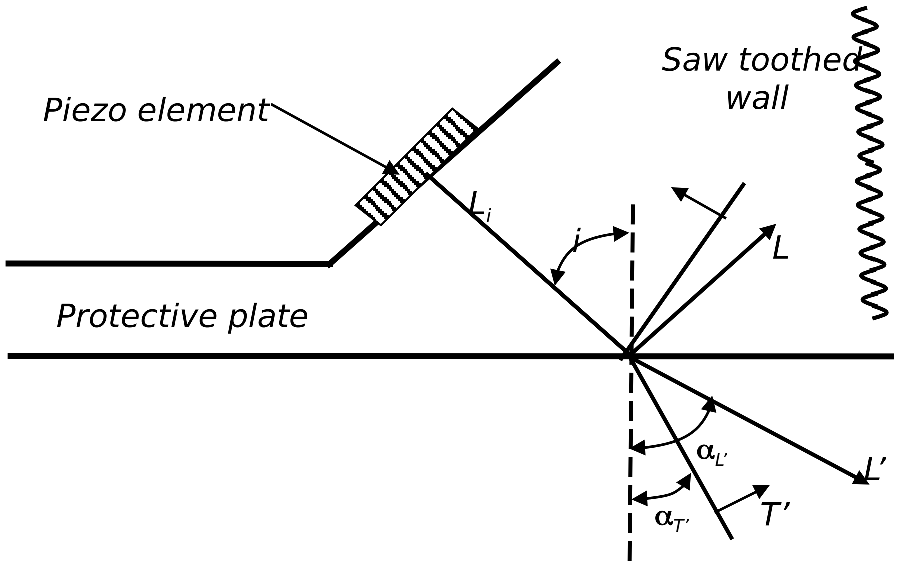
What constitutes a piezoelectric transducer ? (Angle beam transducers case)



Example of a weld inspection

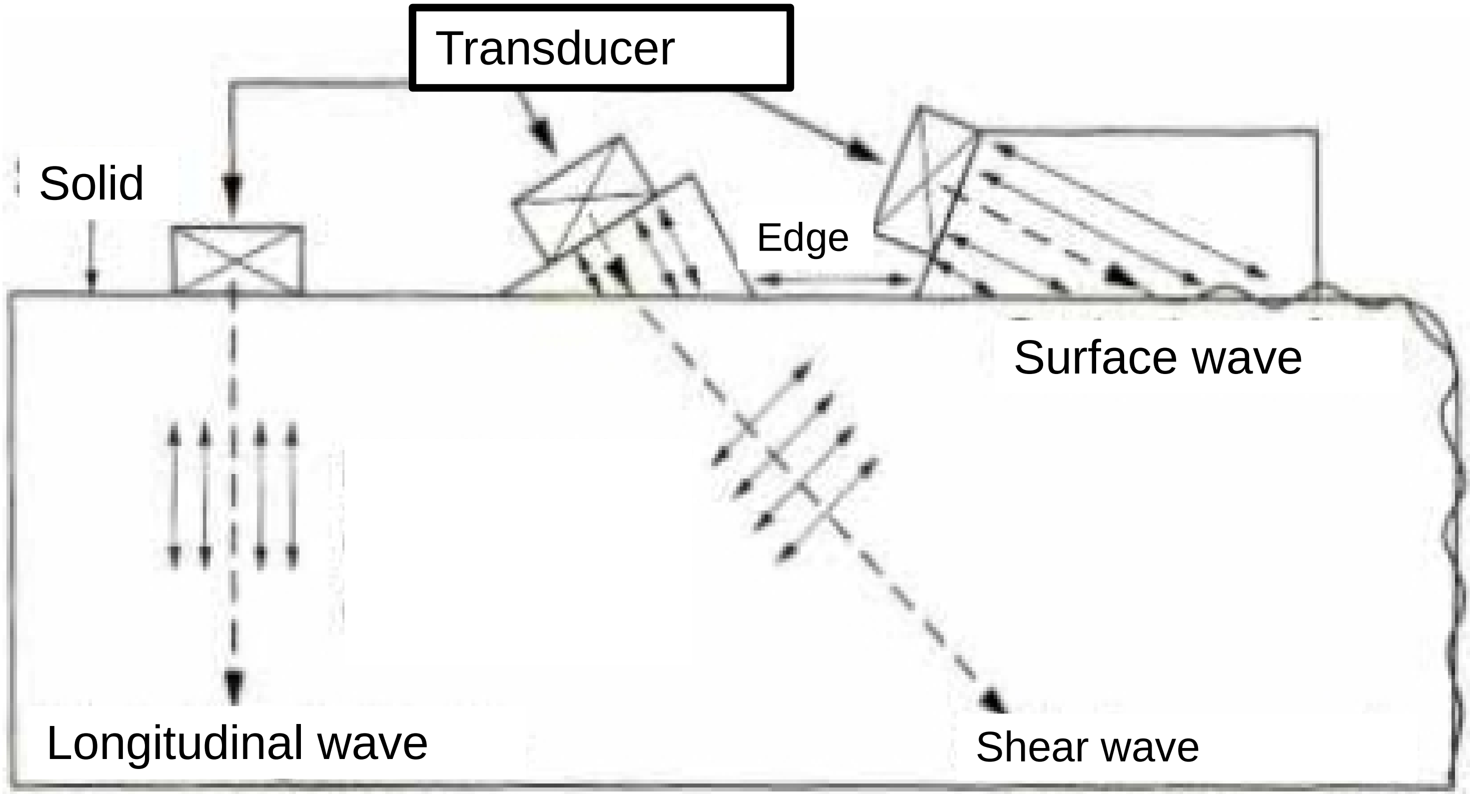


Details of the wear plate



- The angle of the incident longitudinal wave is defined according to Snell's law
- The saw toothed wall avoids multiple reflections

They can be implemented in various manner



The different possible implementations : test modes

We will distinguish the following modes

- Reflection (pulse-echo mode) or Through transmission (pitch-catch mode) or Resonance mode

- Contact mode vs Immersion mode (coupling medium)
- Non contact mode (no physical contact and no coupling medium)

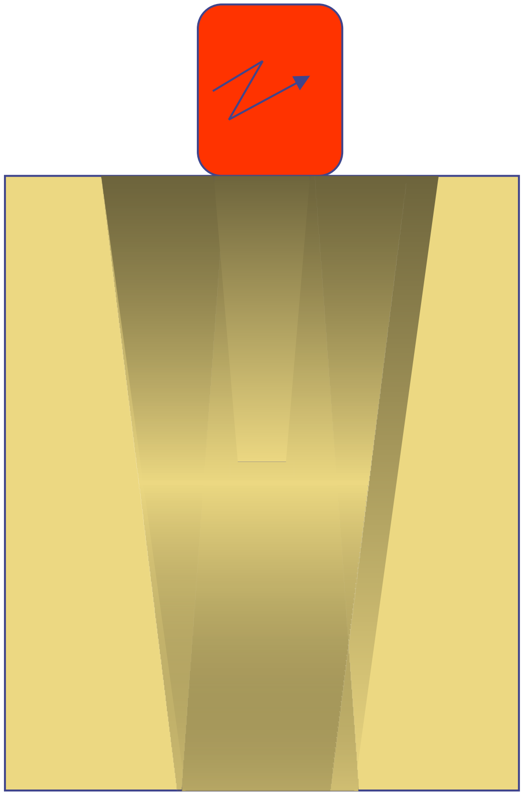
- Normal beam vs Angle beam

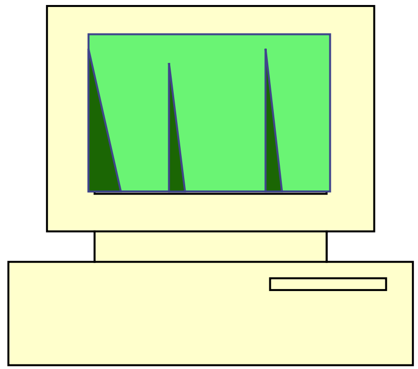
- Manual vs automated

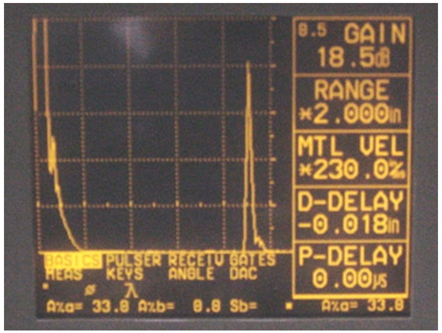
Contact transducers for normal beam inspection

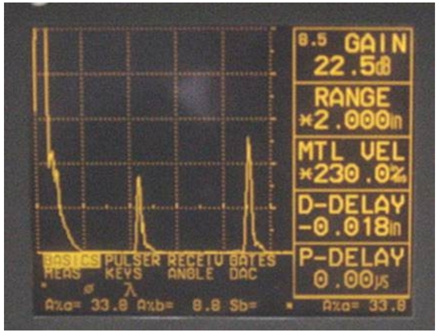
For L and SH waves

Pulse Echo mode (in contact and normal beam)





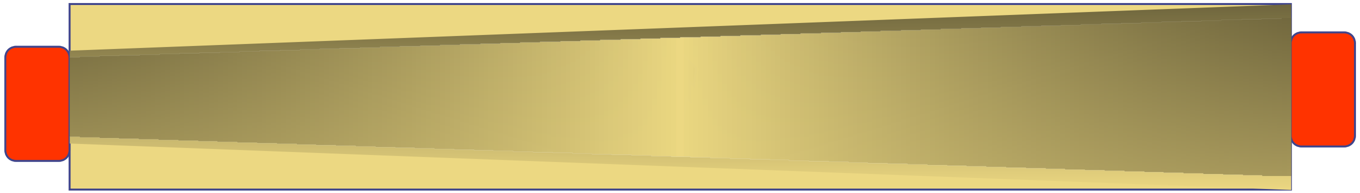




Depth and size of the defect can be assessed

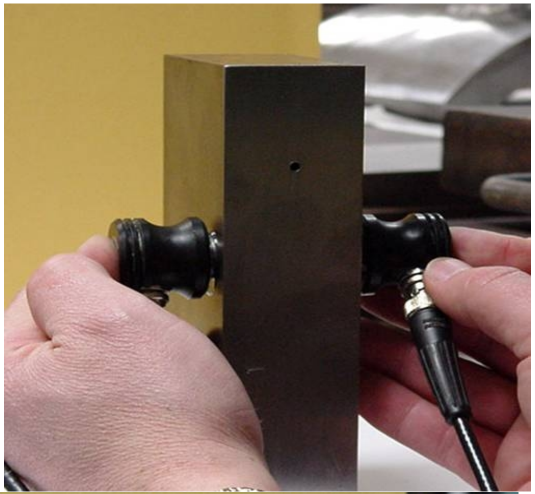
Pitch-catch mode (in contact and normal beam)

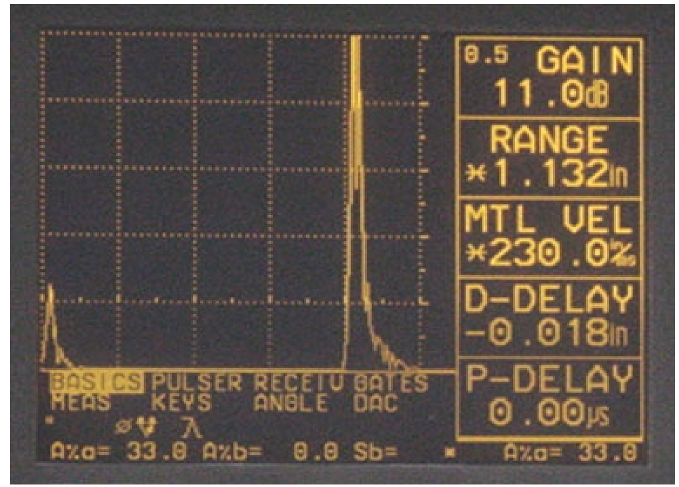
Emitter

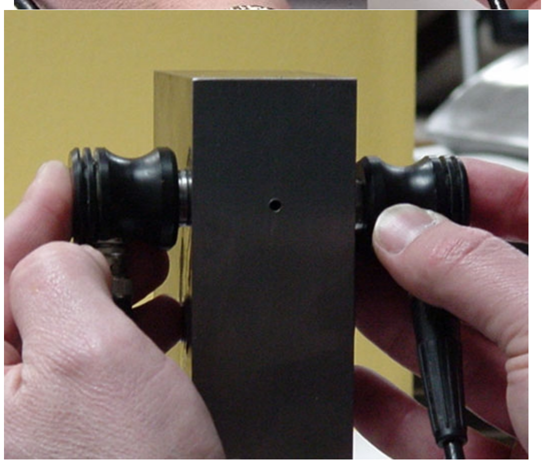


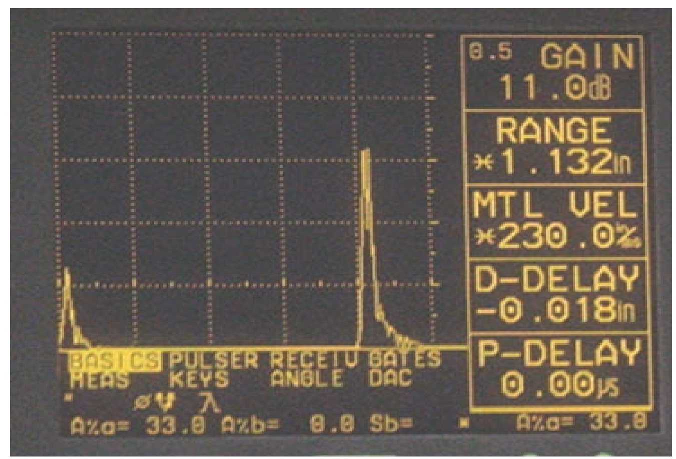
Receiver

No determination of the flaw depth

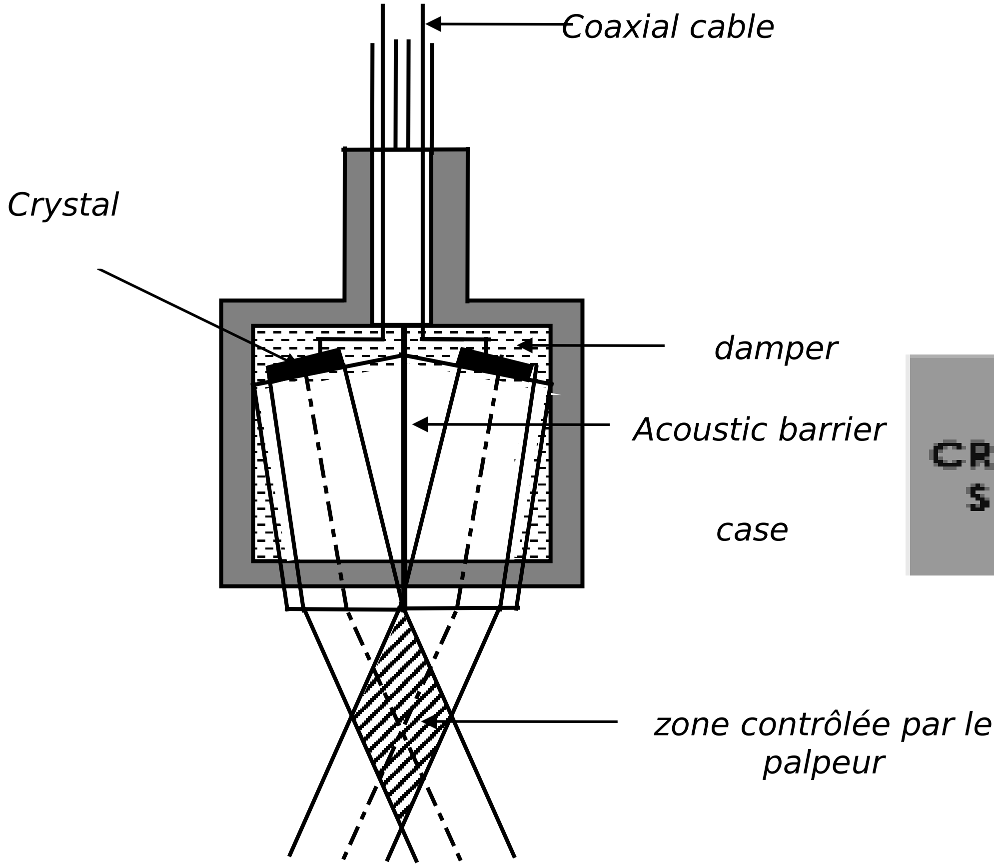


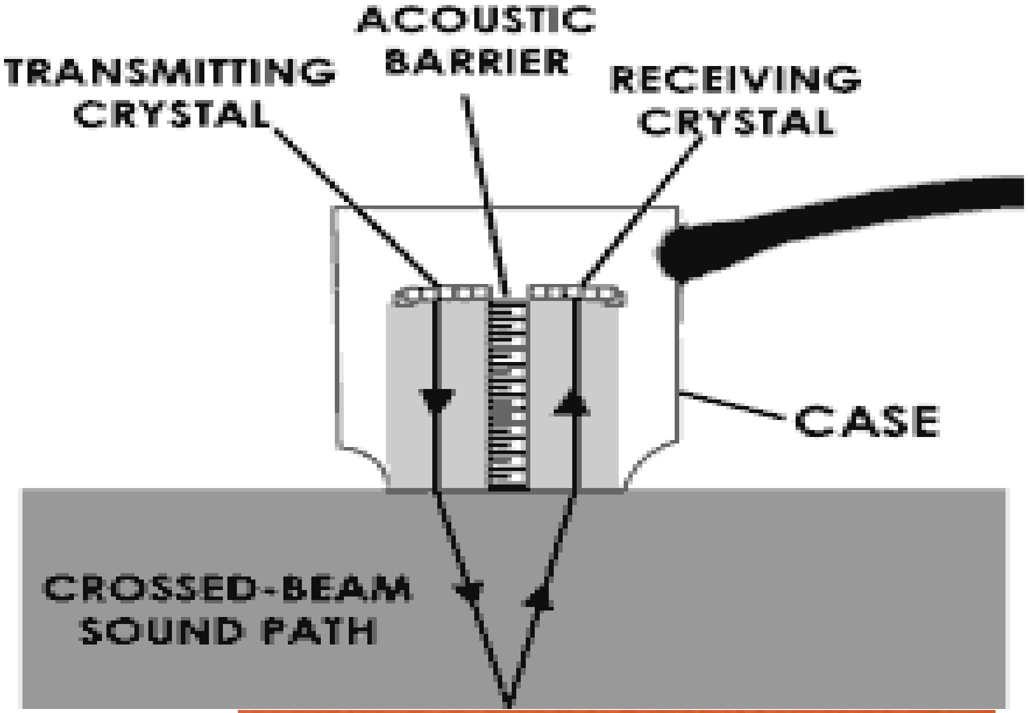


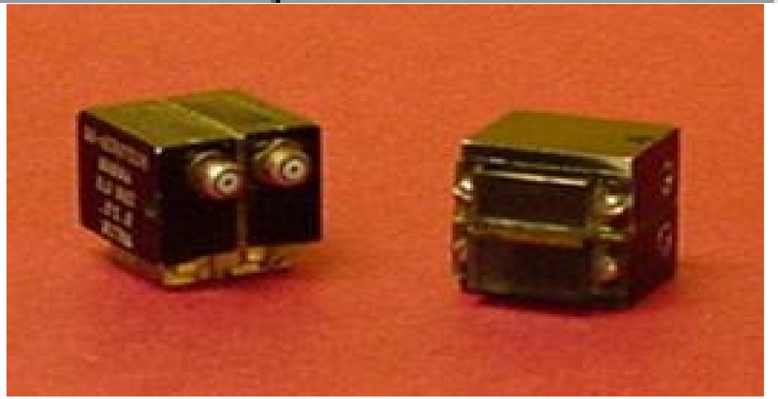




Dual element transducers

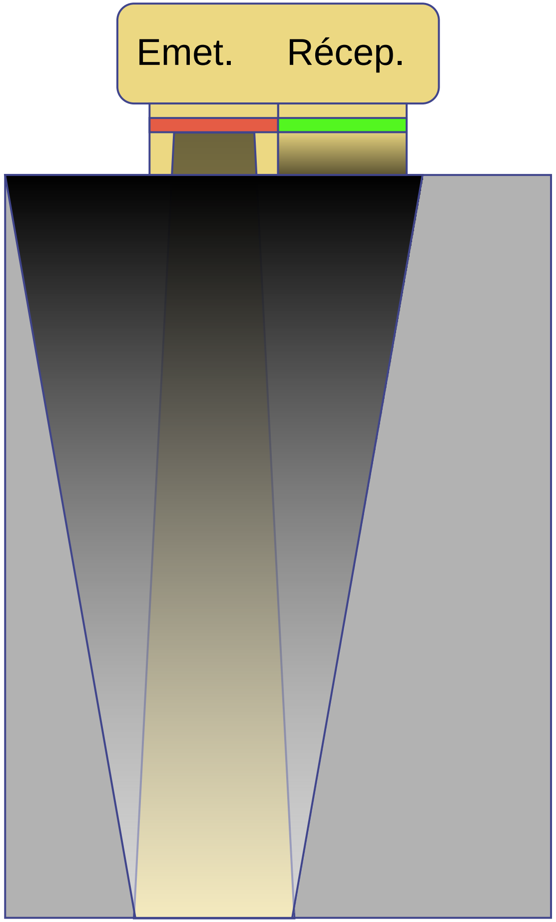




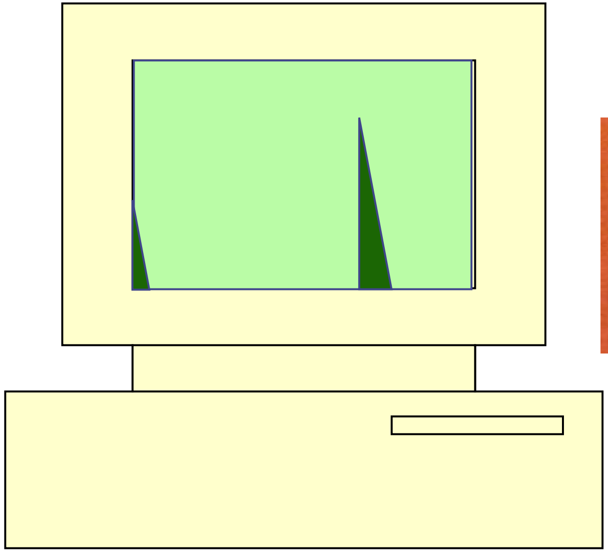


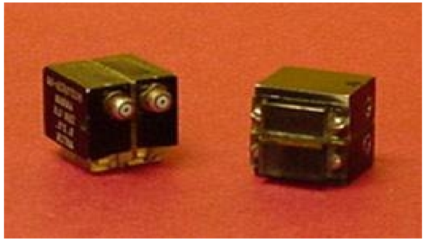
- Used to reduce the dead zone just beneath the surface
- Reduction of the “dead” zone.
- Need of good electronic and acosutic separation of both elements

Pitch-catch mode (manual in contact with dual probe)



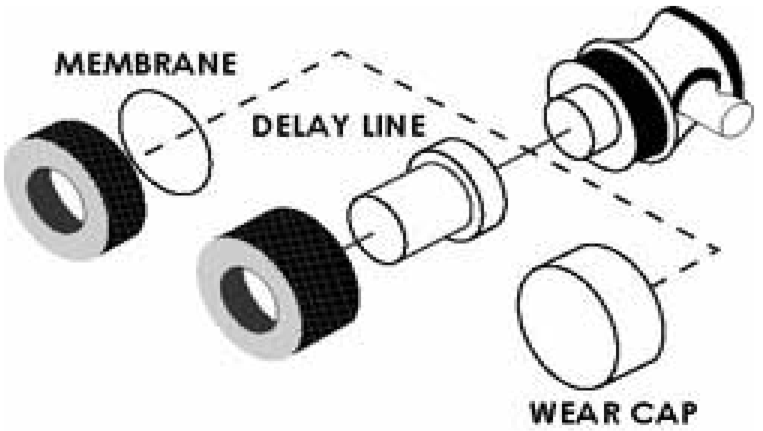
No electrical first echo.

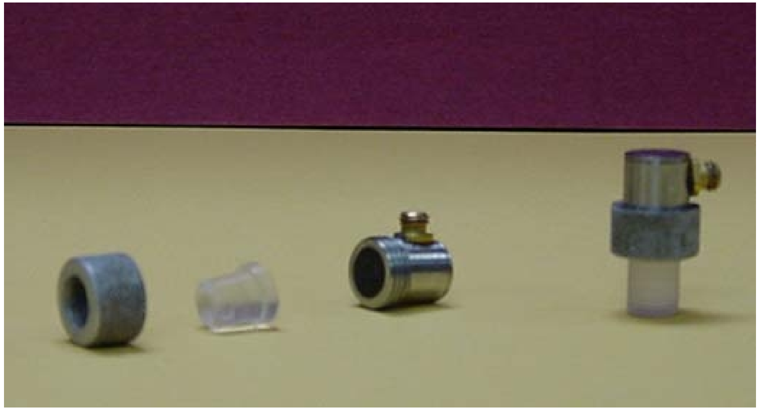




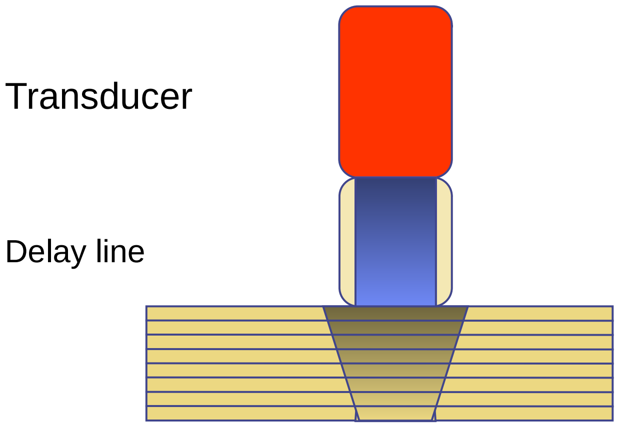
Transducers with delay lines

- Transducer for normal beam mounted on a delay line that allow to move apart the transducer from the surface to be tested (high temperature applications).
- The maximum distance that that can be tested is defined by the lenght of the delai line end the ration of the velocities in the material under test and the delay line.

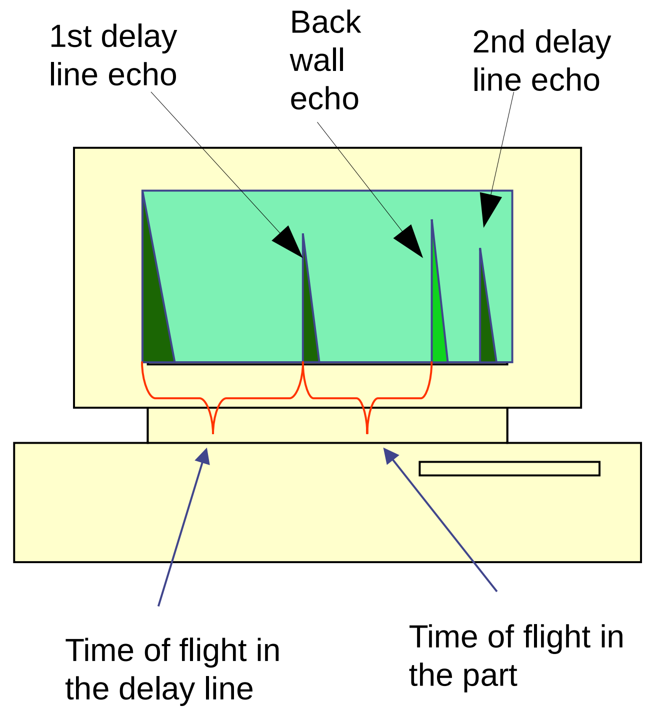




Use of delay lines (contact, manual,

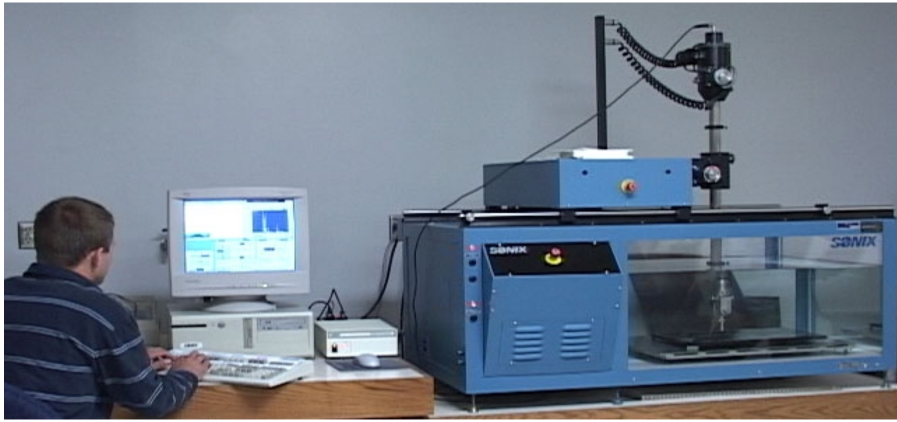


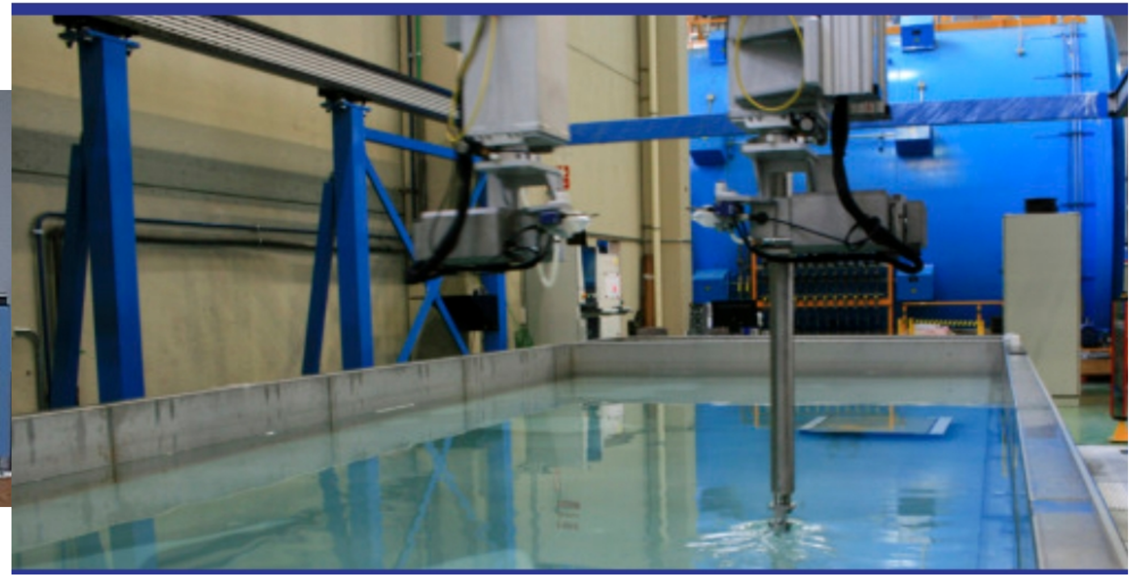
Example: composites testing



Your work :
Explain how to evaluate the maximum depth that can be tested as a function of : the delay line length, the velocities in the two media

Total immersion mode

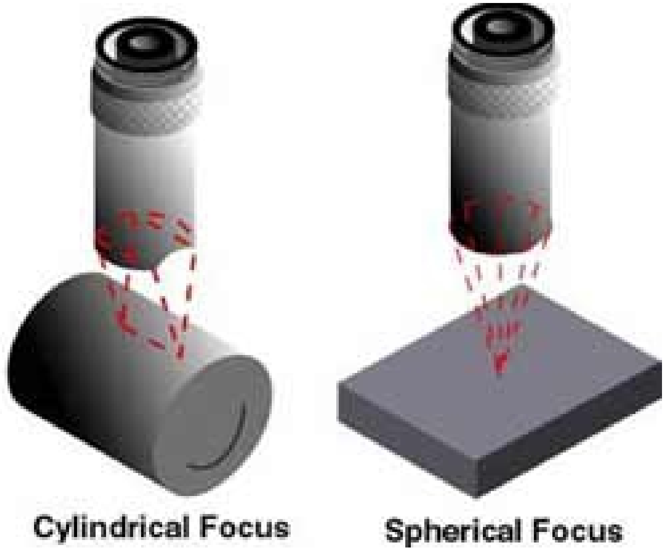




The part to be tested and the transducers are totally immersed in a water tank. Thanks to an automated mechanical system, the transducer can scan the part.

The water tanks can be several tenth of meter long (tube inspection).

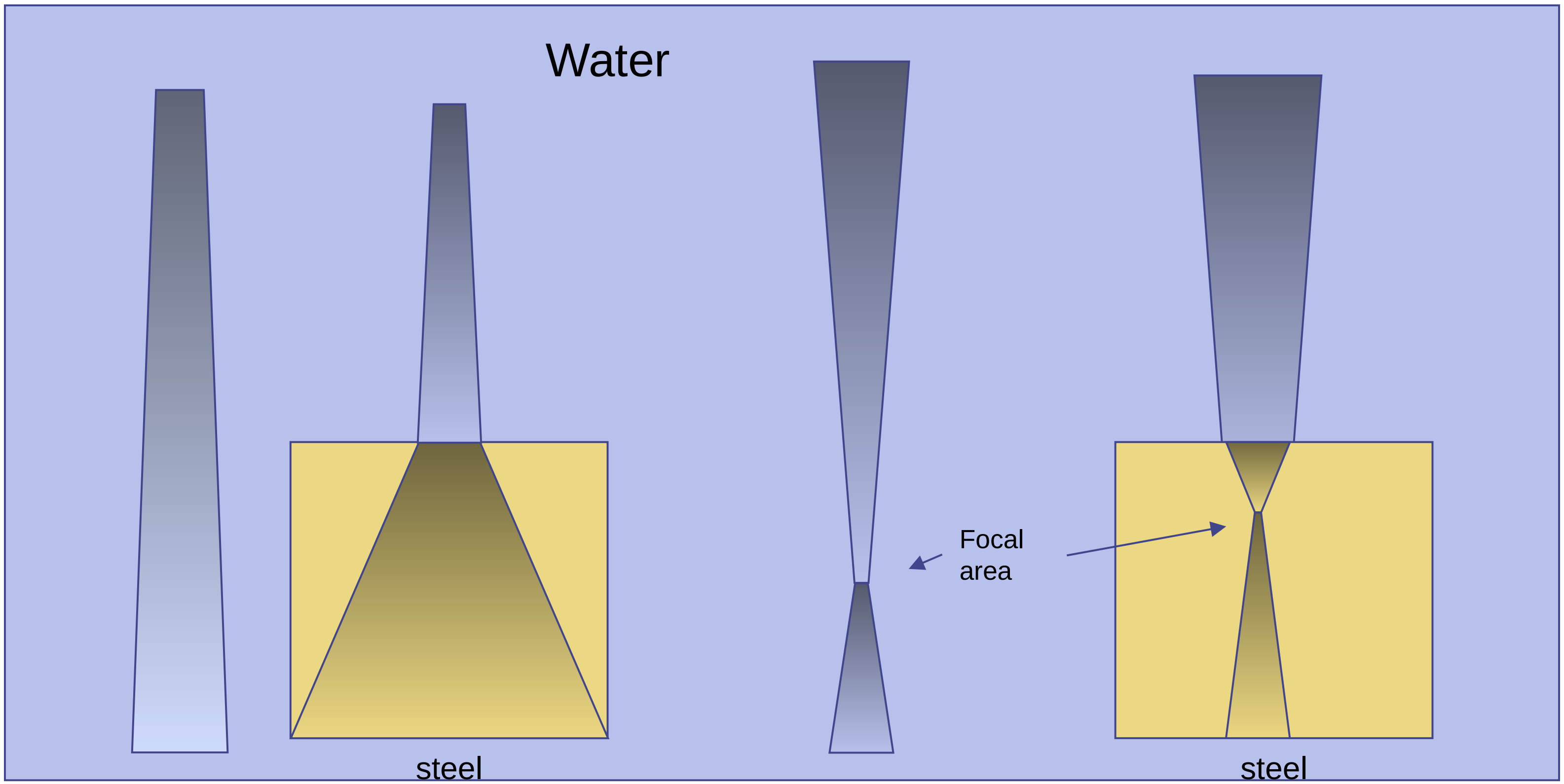
Immersion transducers



Imersion

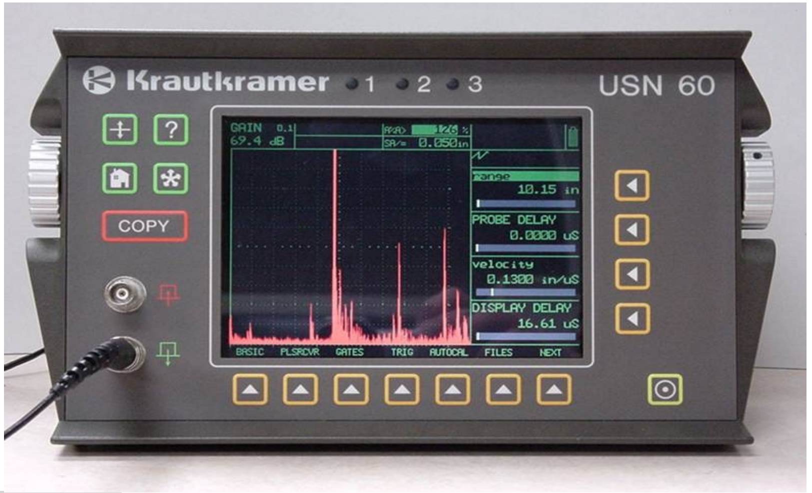
Normal beam transducers

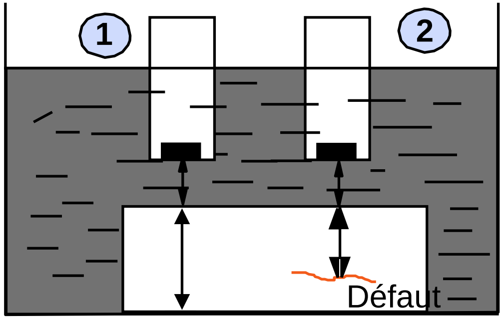
Focused transducers

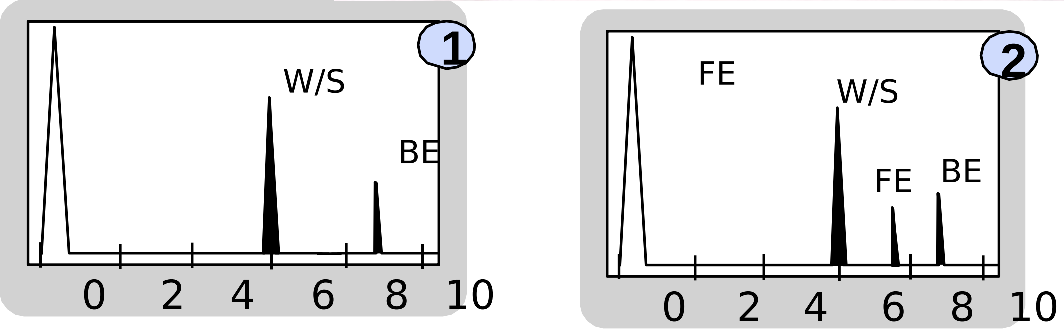


Settings for an immersion test

- W/S water/steel interface
- BE : Back wall echo
- FE: Flaw echo







What can be the problems with respect to the choice of :

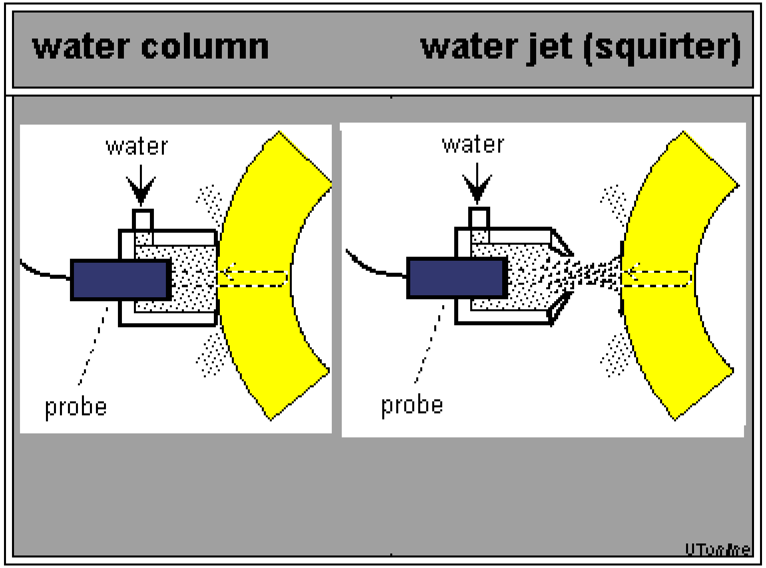
- the water path ?
- the repetition rate of the electrical pulse

Pärtial immersion techniques

- ***Water box transducers :*** the tranducer is maintained at a few cm of the surface to be tested into a case filled with water. Soft joins prevents the leaks.
- ***Water jet technique :*** . A tube projects a liquid under pressure. The US beam is guided to the surface. The lenght of the water colomn can reach 10 to 20 cm for diameters of 2 to 10 cm.
- ***Rolling scanner***

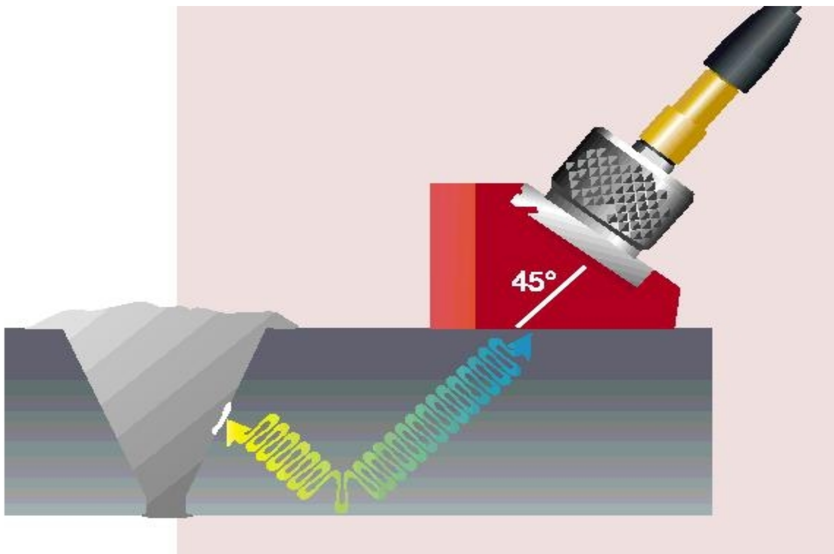
  Modern versions of water box technique

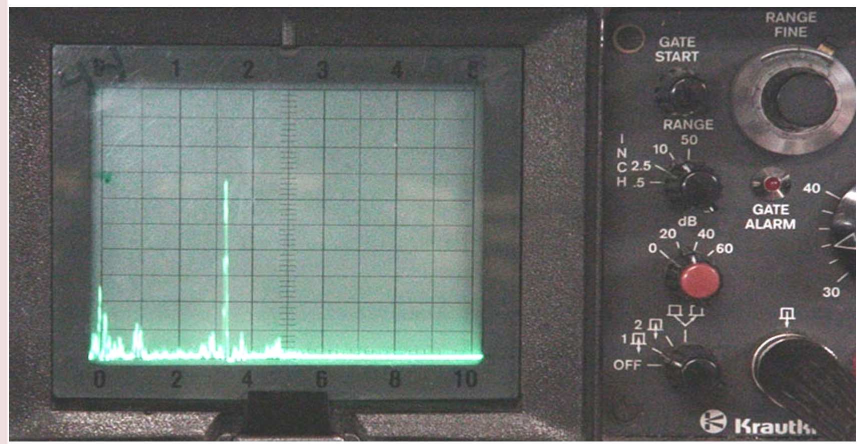
  Exists for normal or angle beam and even for phased arrays



Angle beam method

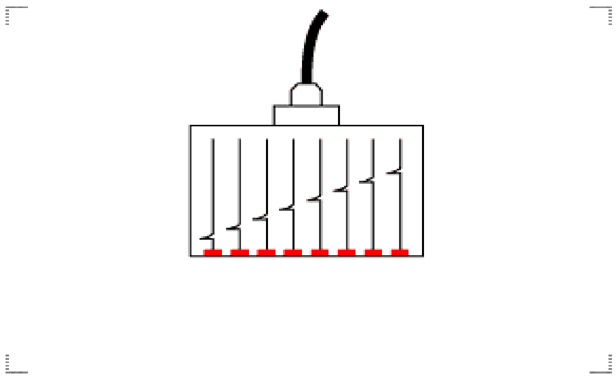
- Can be implemented either in contact or in immersion



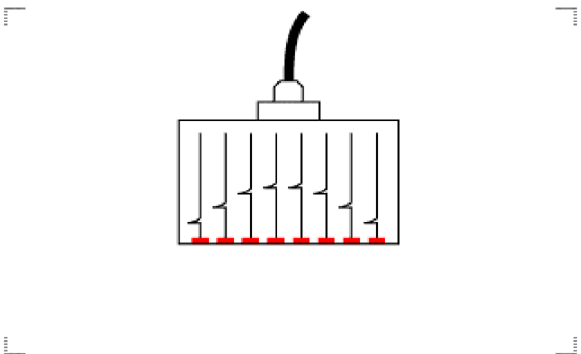


Array transducers

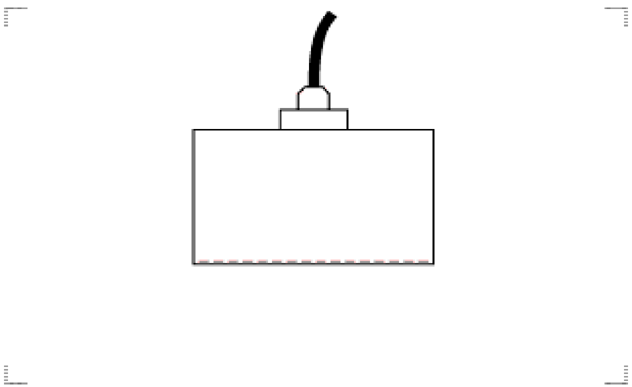
Deflection



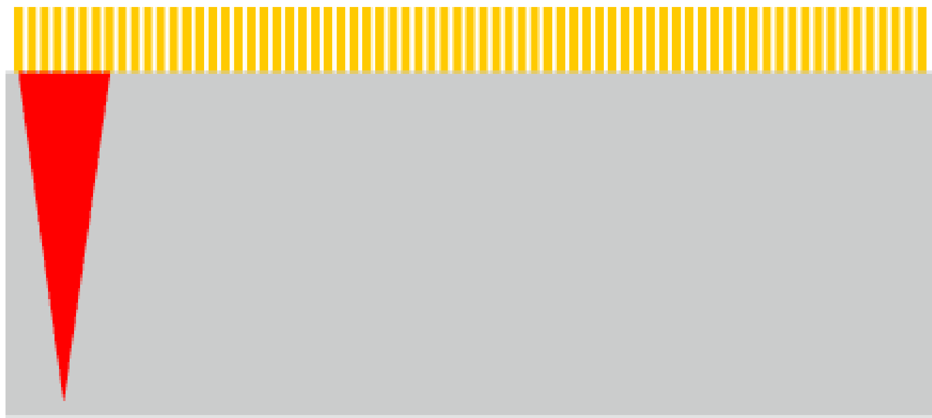
Focalisation

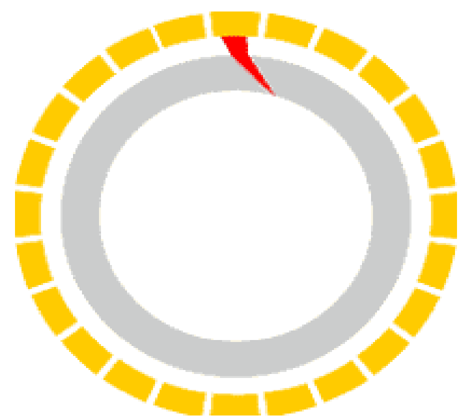


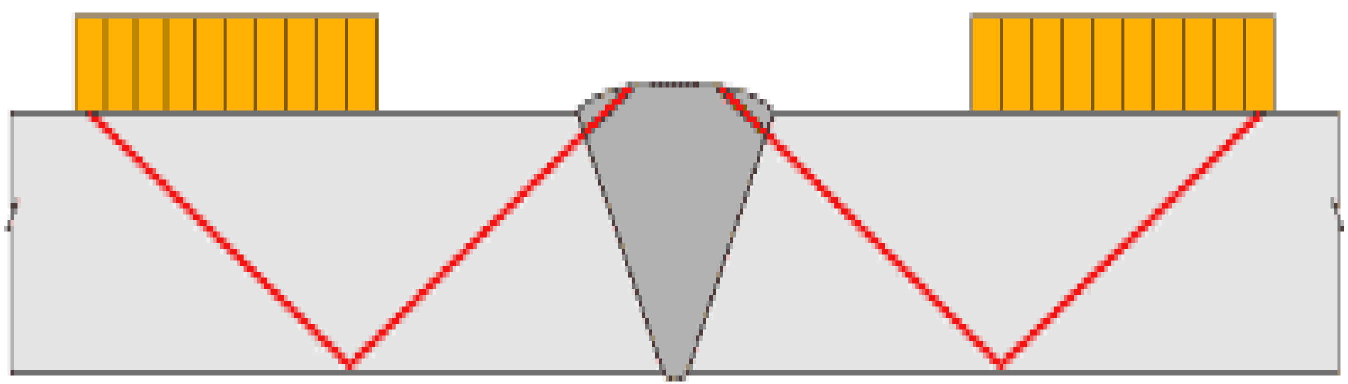
Scanning + focusing



Phased array transducers





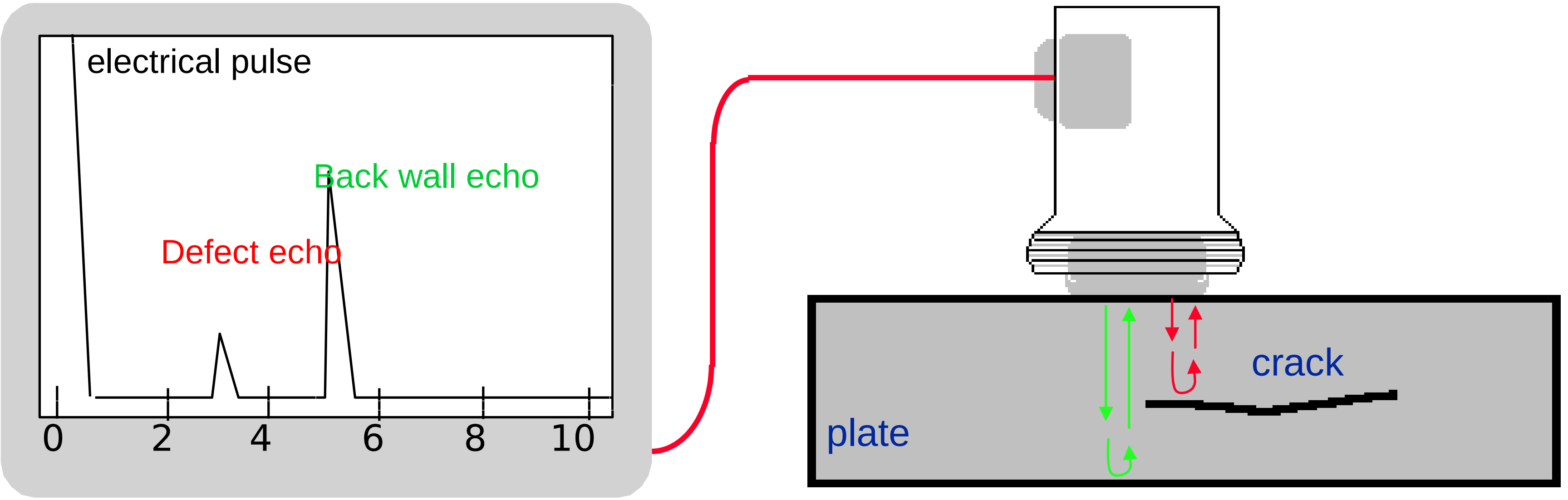


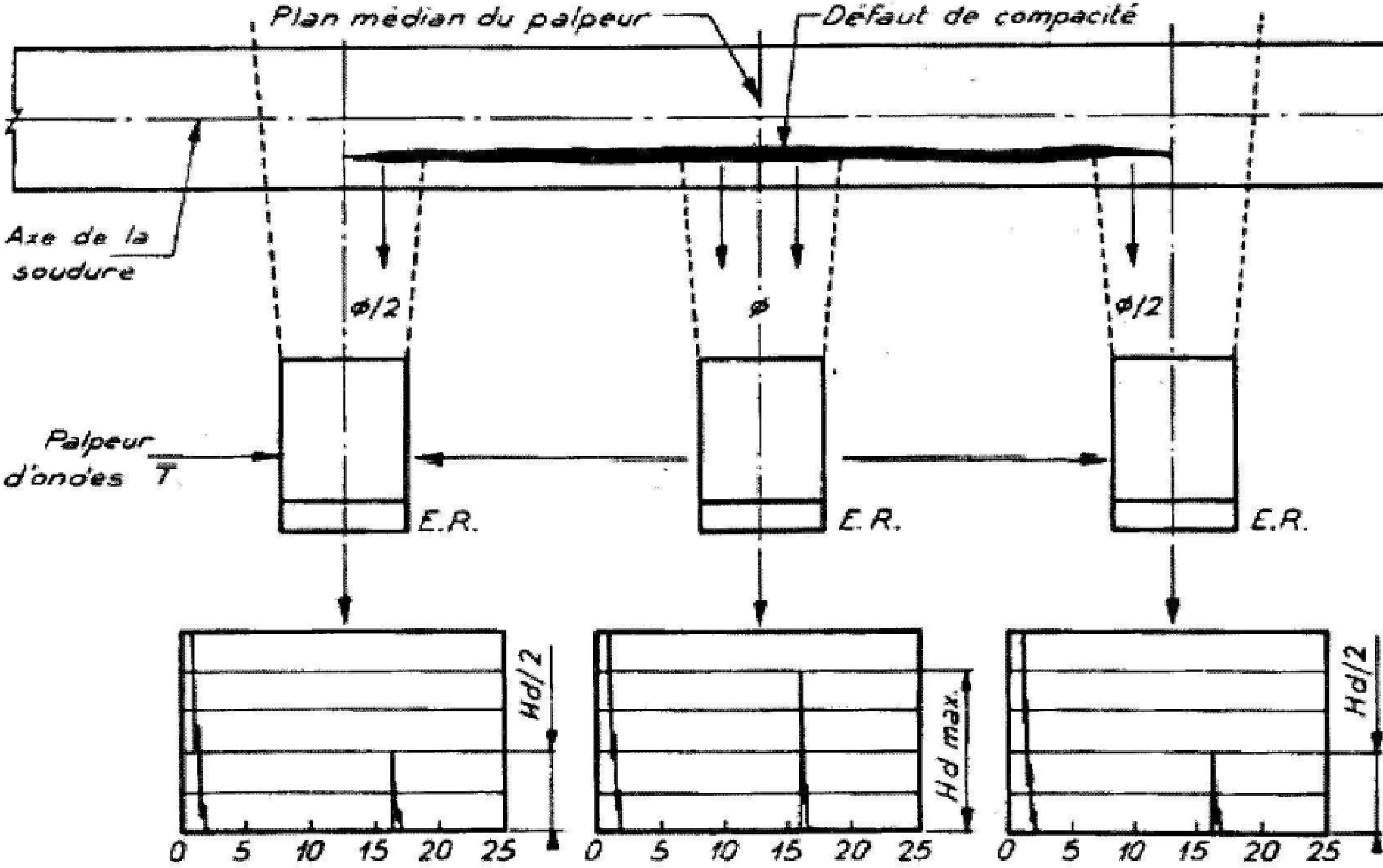
Flaws sizing methods

- 6dB drop method
- Distance Amplitude Correction (DAC)
- Distance Gain Size method (DGS (en) or AVG (german)).

Implementation of the 6dB drop method

- The transducer is moved in front of the test specimen and the A-scans are observed. When a flaw is detected, we seek for the center of the flaw. If the defect is wider than the beam, the backwall echo disappears and the amplitude of the echo is calibrated to 80% of the screen.
- Then the edges are found when the DE is divided by 2 (-6dB).

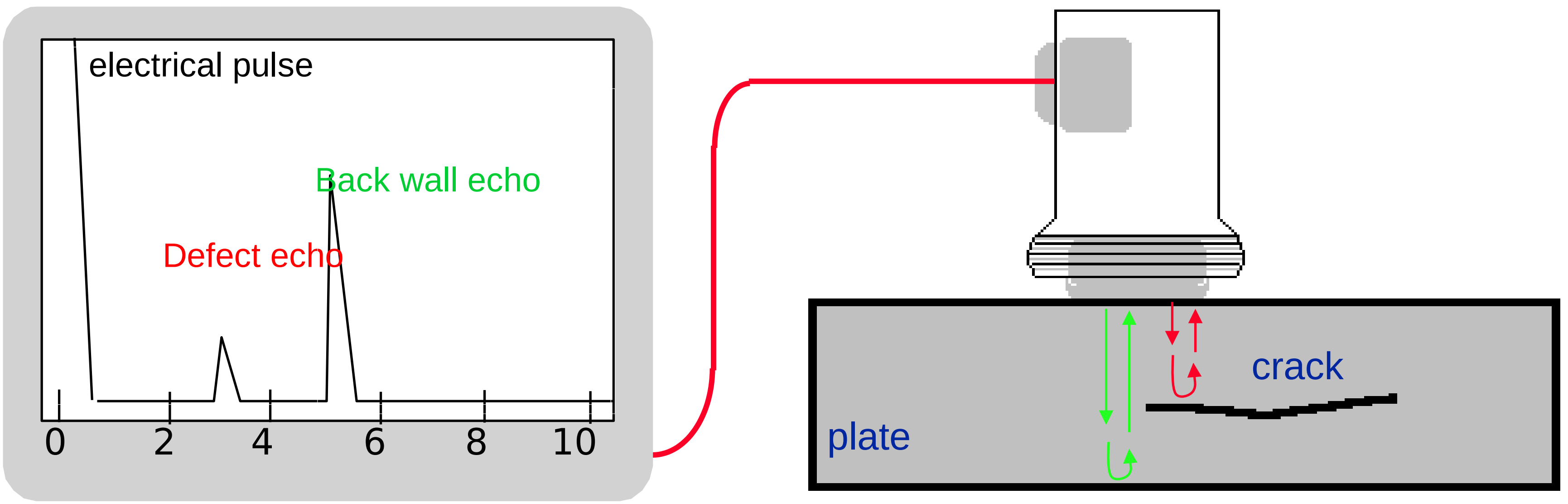




Plan médian du palpeur
Défaut de compacité
Axe de la soudure
ø/2
ø
ø/2
Palpeur d'ondes T
E.R.
E.R.
E.R.
Hd/2
Hd max.
Hd/2
0 5 10 15 20 25
0 5 10 15 20 25
0 5 10 15 20 25

Implementation of the 6dB drop method

- In practice, we can use a compensation method, by adding 6 dB to the gain and the find the positions for again DE at 80% of the screen)
- This method can be performed in an automated way. C-Scan images + contour detection at -6dB or by steps of -6dB (-6dB, -12dB, -20db etc...) according to the used standards.



Oscilloscope, or UT device

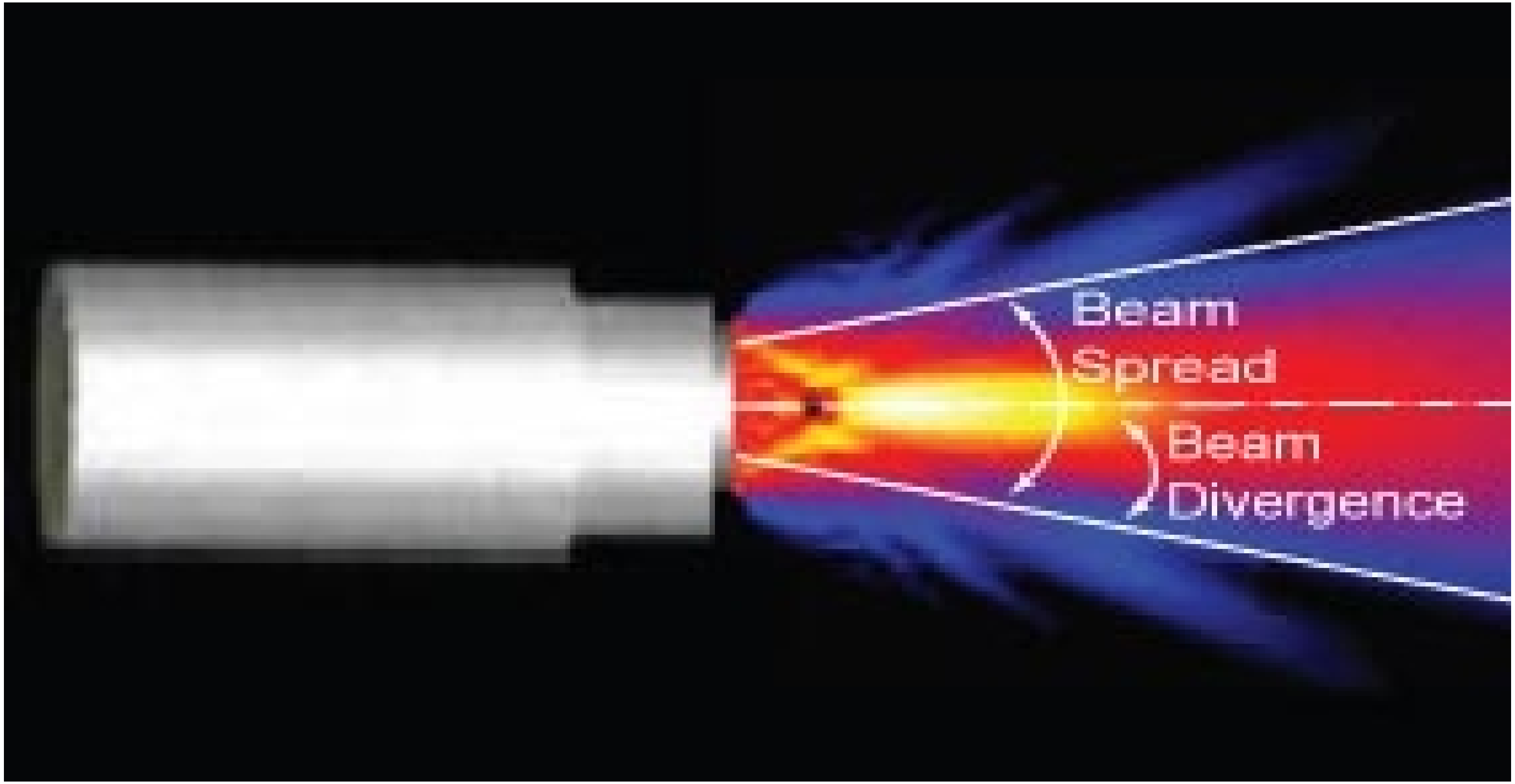
Limitations of the method

- dues to the defect:
  - Dimension must be larger than the beam diameter
  - Good orientation
  - Inhomogeneity of the flaw surface
- dues to the beam
  - Beam must be symetric
  - Diffraction free
  - Limited to normal beam inspection
  - coupling
- dues to the material
  - Inhomogeneity
  - Attenuation

Validity of the results

- **Any discard to the perfect conditions will lead to an under evaluation of the size.**

How to account for actual beam structure ?



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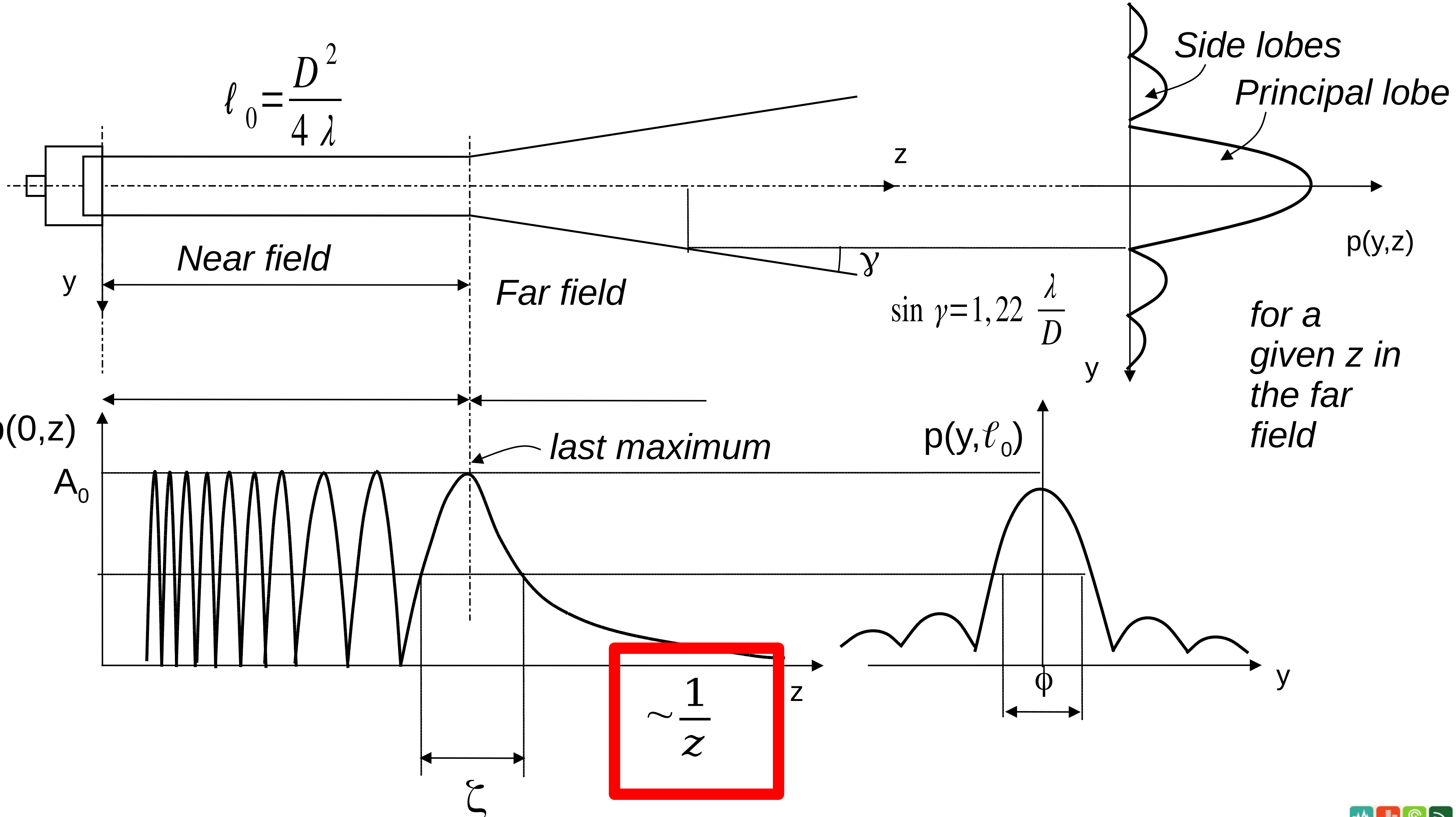
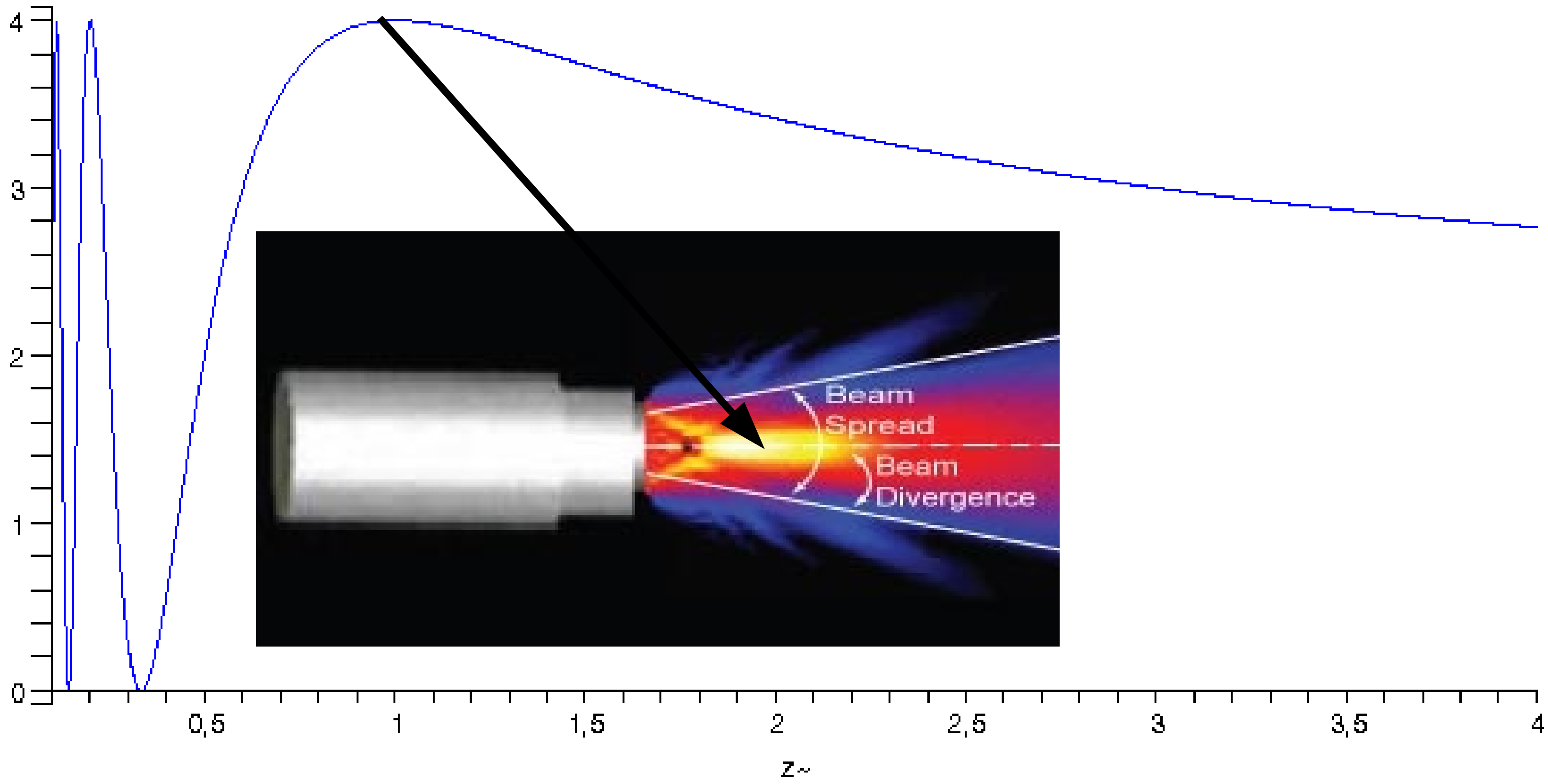
Properties of the beams (from diffraction theory)



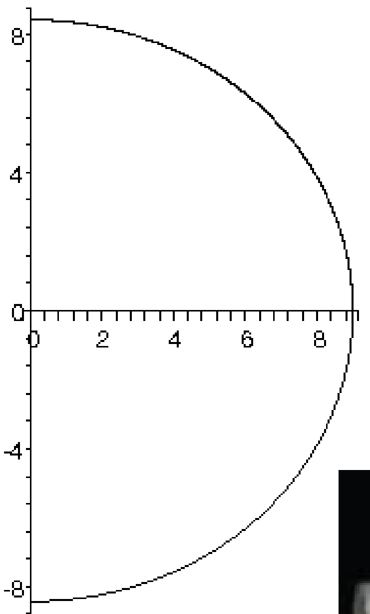
Calculation for un radiating disk



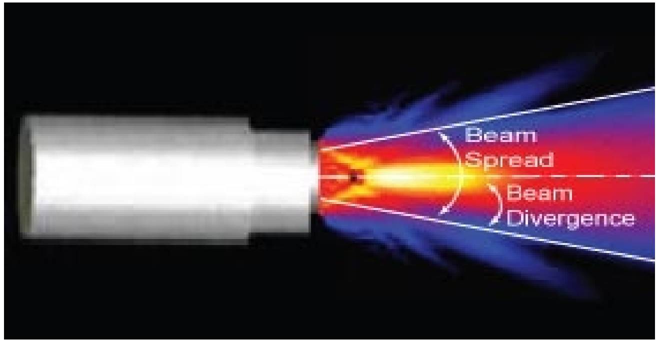
Radiation diagram in the far field of a single source

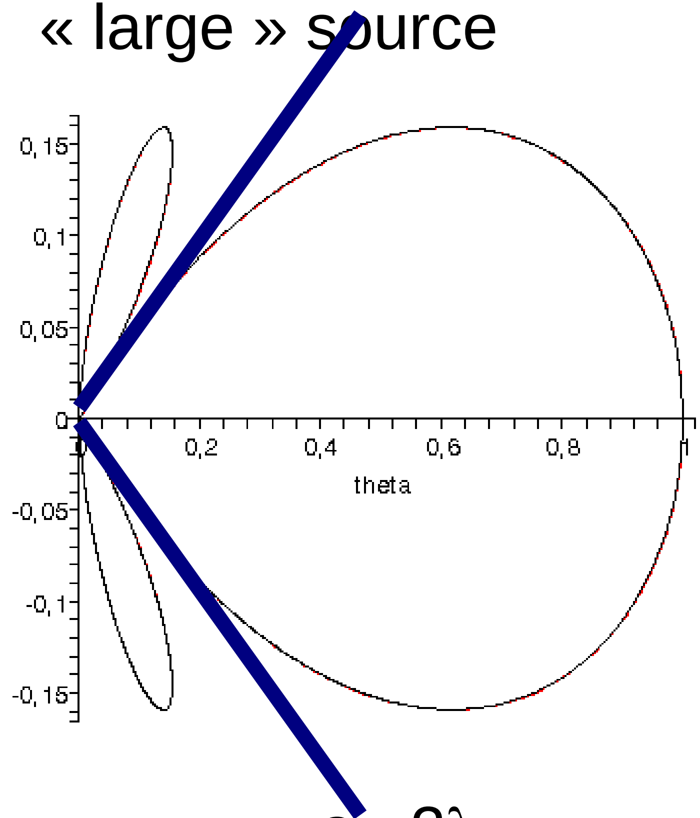
Quasi-ponctual source

« large » source



a= λ/5

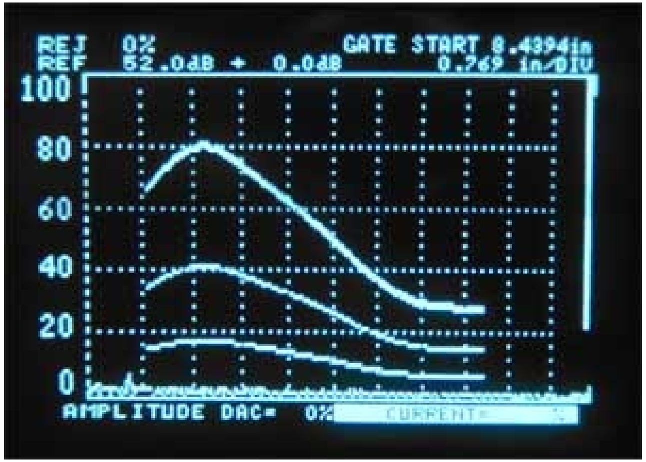




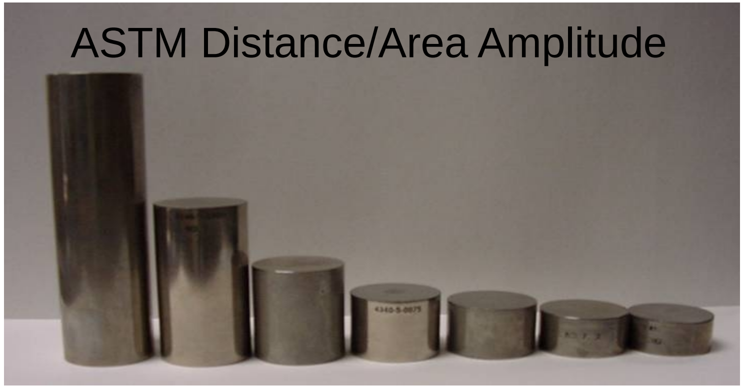
a= 2λ

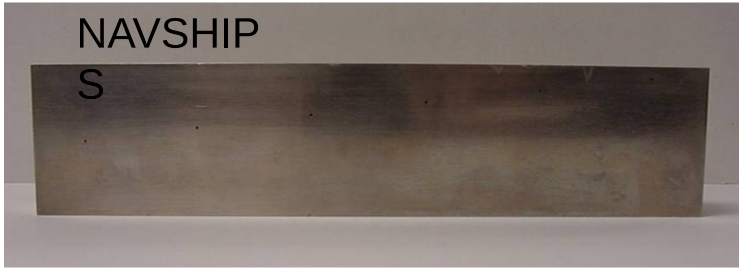
DAC Method

- Very empirical approach
- Takes into account the actual shape and characteristics of the beam : Beam illustration
- Utilize standard flat bottom holes or side drilled holes to establish known reflector size with changes in sound path from the entry surface
- Plots several DAC curves A = f(d) with the hole diameter as a parameter
- When a flaw is detected at a given depth its amplitude is compared to the DAC curves defined previously
- Can be used in angle beam inspection.



see applet


ASTM Distance/Area Amplitude

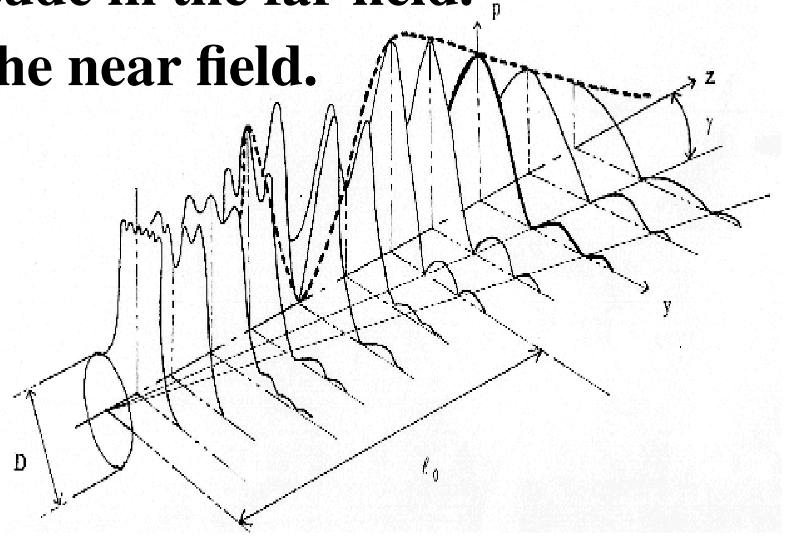

NAVSHIPS

Limitations of the method

- dues to the defect:
  - Dimension smaller than the beam
  - good orientation
  - Defect is considered as an equivalent FBH
- Dues to the beam
  - Valid for a given transducer, and a given setup (gain, frequency ...)
  - The conditions for the drawing of the DAC curves must be known and excatly reproduced.
  - coupling
- Dues to the material
  - DAC must be obtained on a material with properties very close to those of the material to be tested.
  - Homogeneity

DGS Method

- Calculation of the field radiated by the transducer
  - Calculation of the reflection on a very large reflector normal to the beam axis.
  - Calculation of the reflection on small reflectors normal to the beam axis.
- Calculation of the reflected received amplitude in the far field.
- Experimental completion of the curves in the near field.
- Plotting of universal curves



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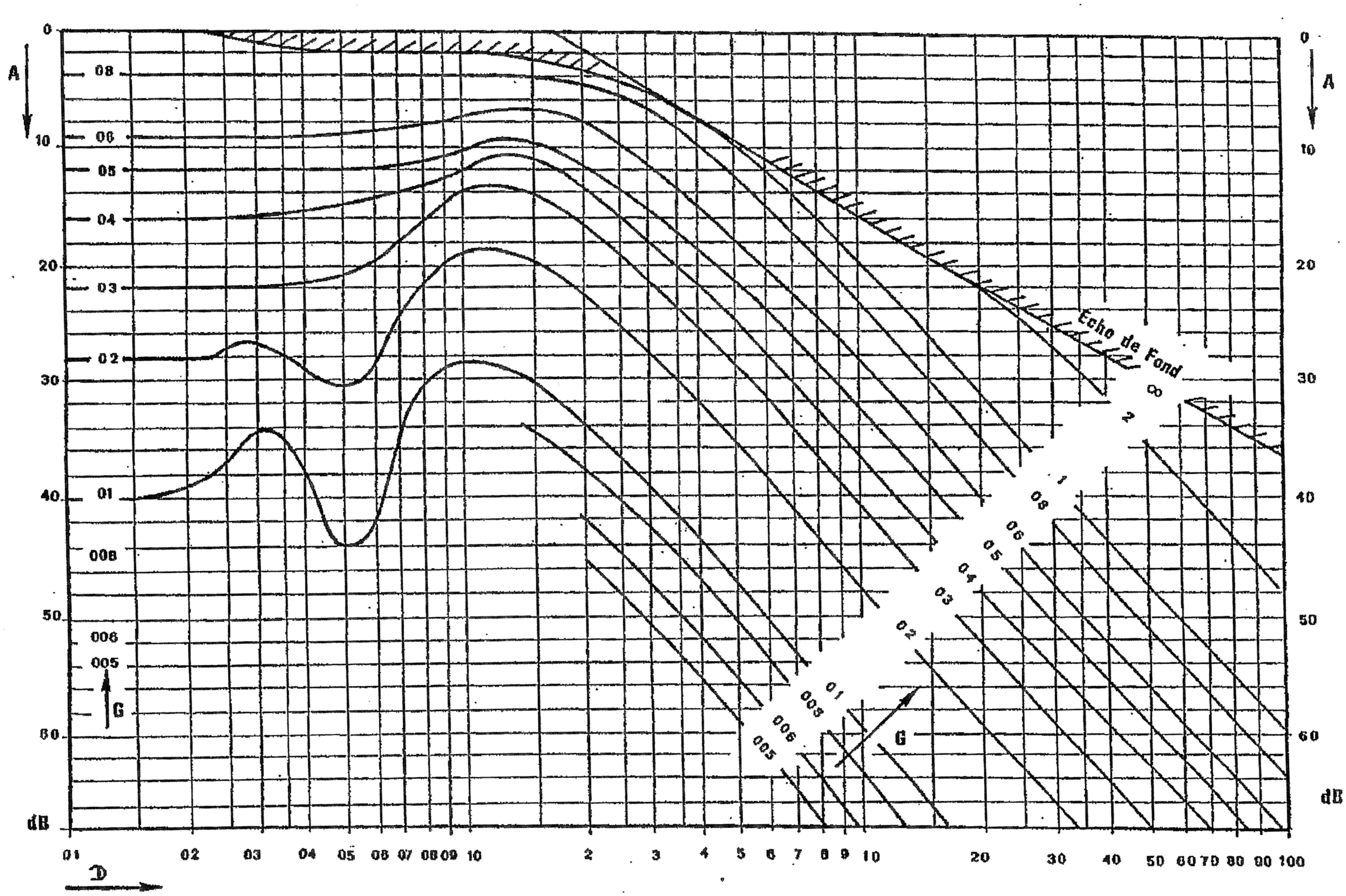
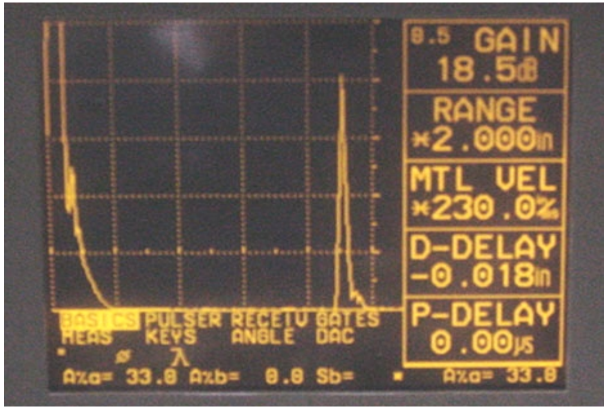
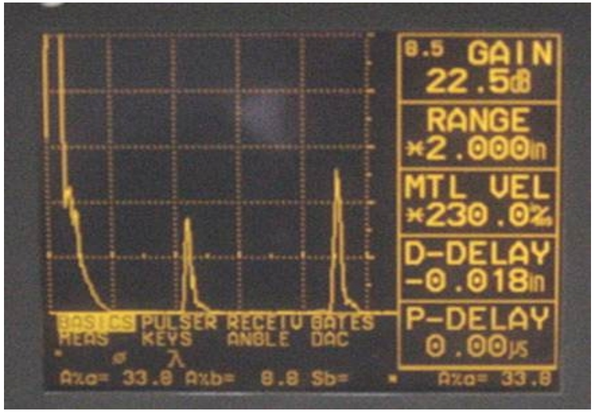
DGS Curves description



Exercice



v=230 ''/ms=5842 m/s



Depth of the back wall echo :
zf=4,5*2/5 =1.8 ''

Transducer : Diameter = 0.5'' ; F = 1 MHz

$l_0=(0,5)^2/(4*230.10^3)*10^6=0.27''$

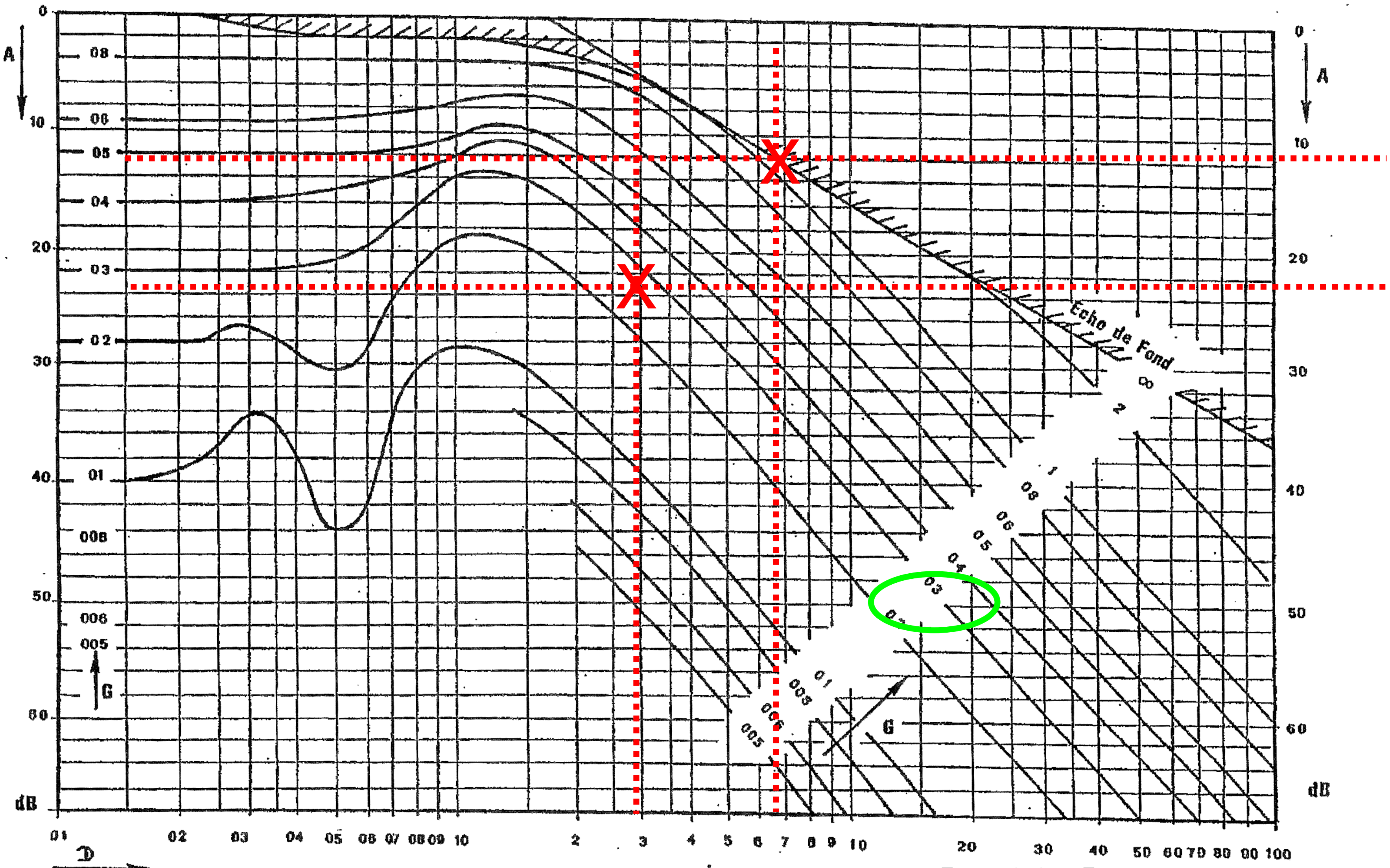
thickness :
Df=1.8/0.26=6,66

Depth of the defect :
zd=2*2/5 =0.8''

amplitude drop :
20*log(1,8/4)-4=-10,93 dB

Defect depth
Dd=0.8/0.27=2.96

How to use the DGS curves ?

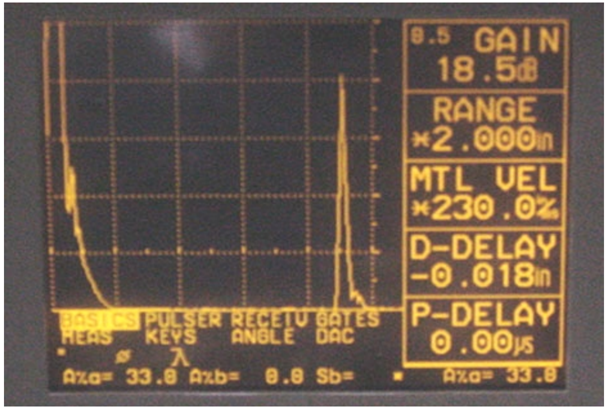


$\Phi_d = 0{,}25\ \Phi_t$

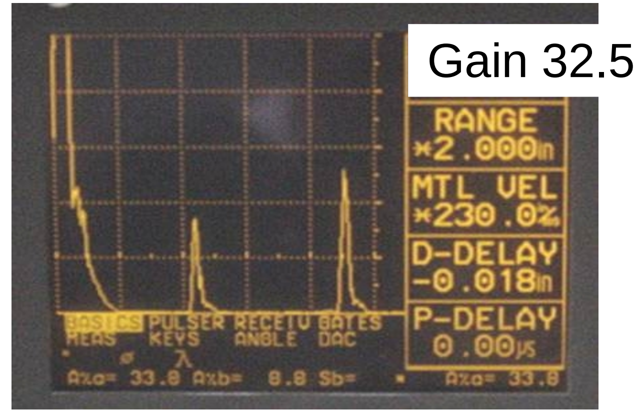
Limitations of the method

- **Valid for a given shape of transducer**
- **L_0 is defined in harmonic regime. In the case of the pulsed regime L_0=90% L_0 (harmonique))**
- **Low absorbion materials (or correction needed)**

Exercice



v=230 "/ms=5842 m/s



Depth of the back wall echo :
zf=4,5*2/5 =1.8 "

Depth of the defect :
zd=2*2/5 =0.8"

amplitude drop : 20 log10(1.8/4) -14=-21

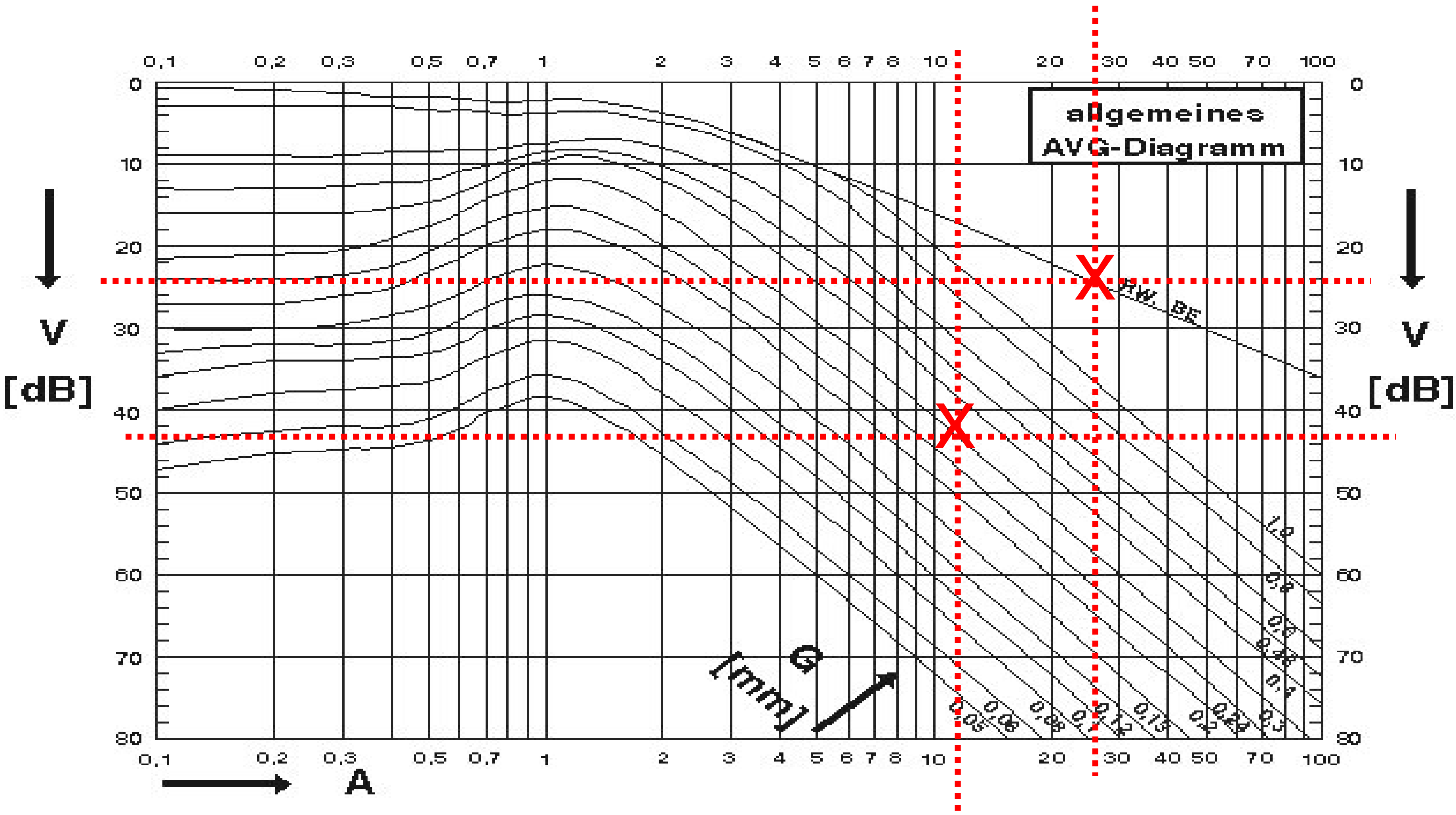
Transducer : Diameter = 0.25" ; F = 1 MHz

l_0= (0.25)^2*1e6/4/0.23=0.06”

thickness :
Df= 1.8/0.06=30

Defect depth
Dd= 0.8/0.06=13

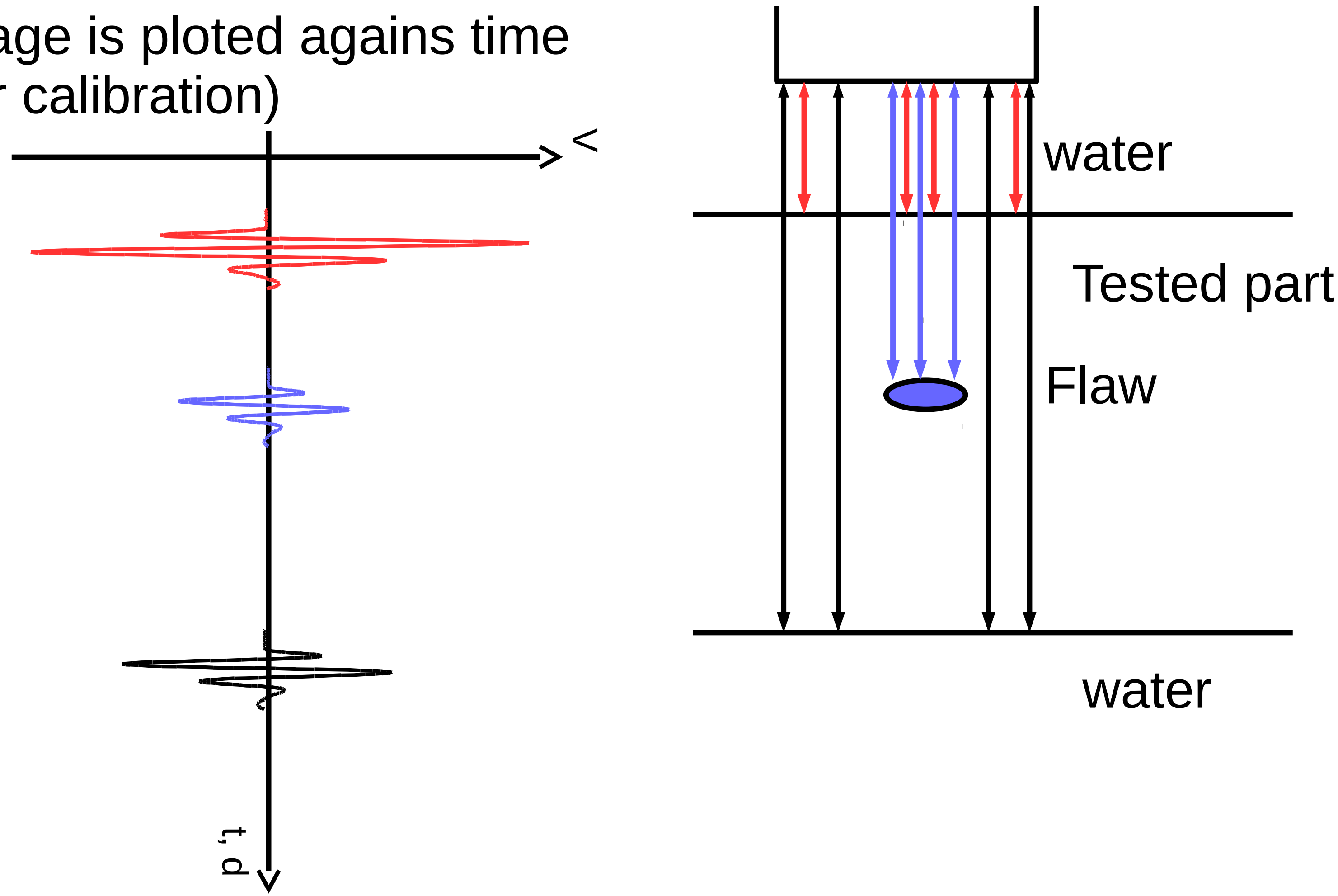
How to use the DGS curves ?



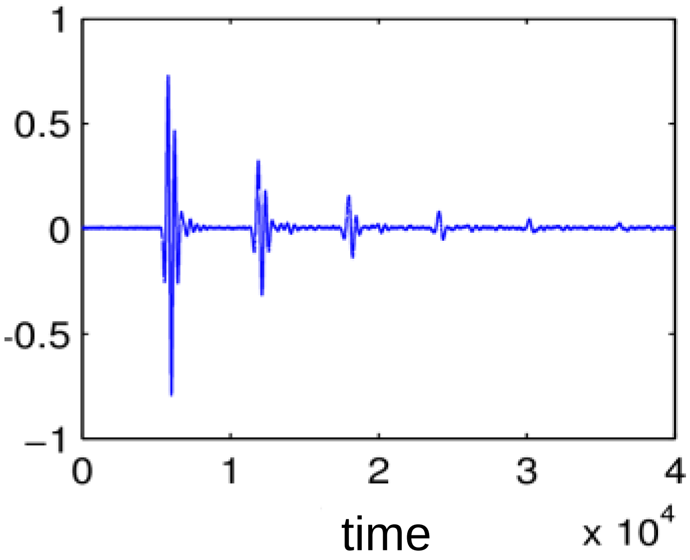
Data presentation

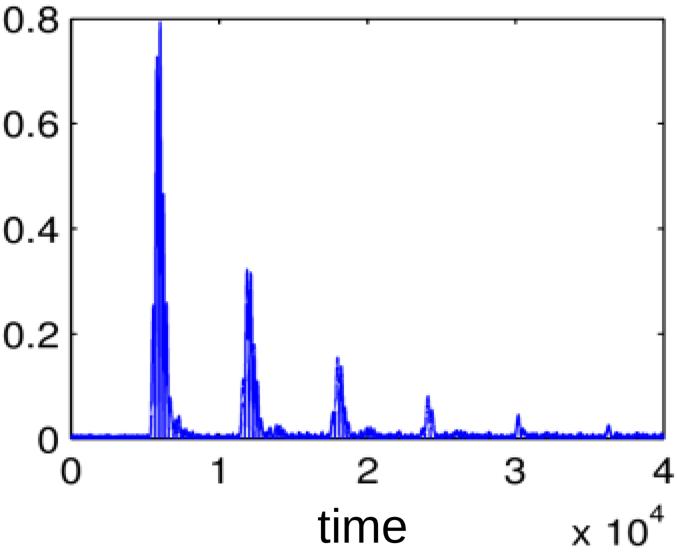
A-scan presentation

Point measurement
The receive voltage is ploted agains time (or distance after calibration)

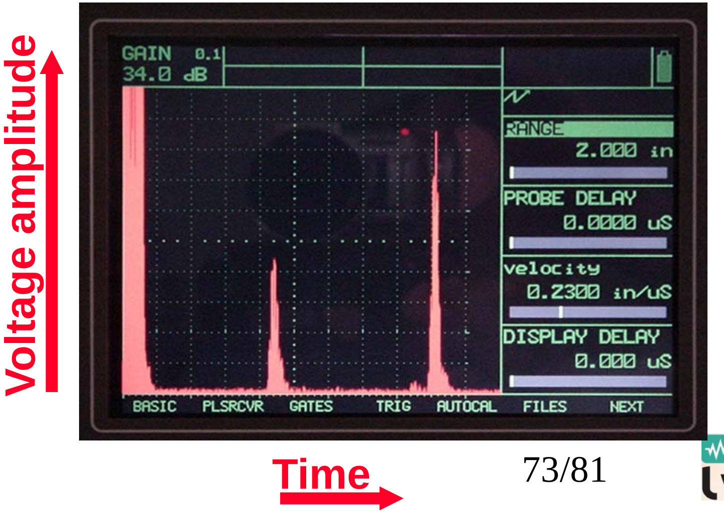


A-scan data presentation





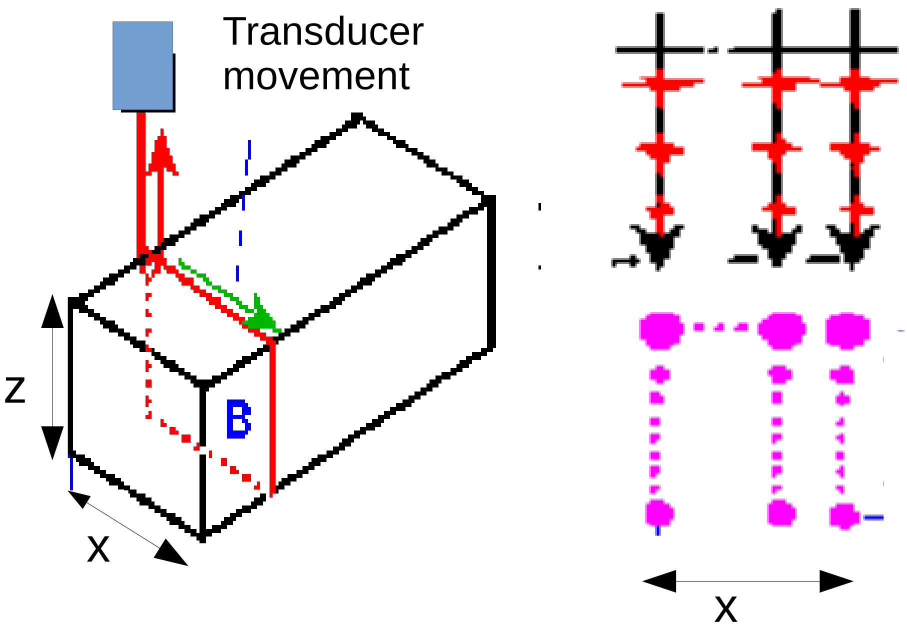
- The depth of a flaw can be estimated directly

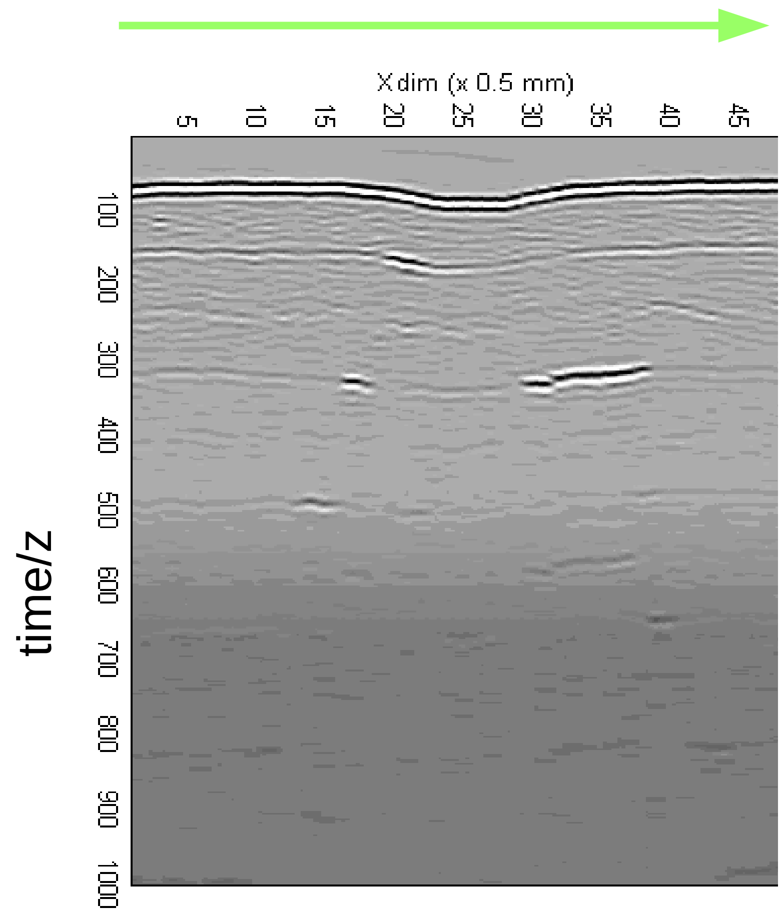


B-scan presentation

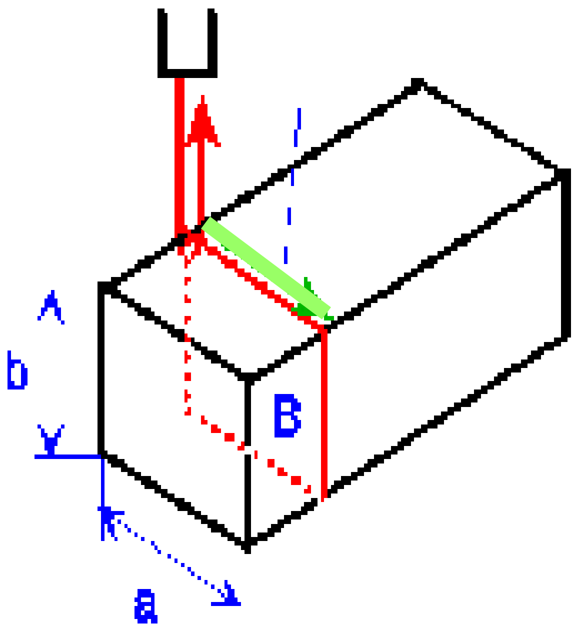
The B-scan presentation is a cross-section of the tested part.

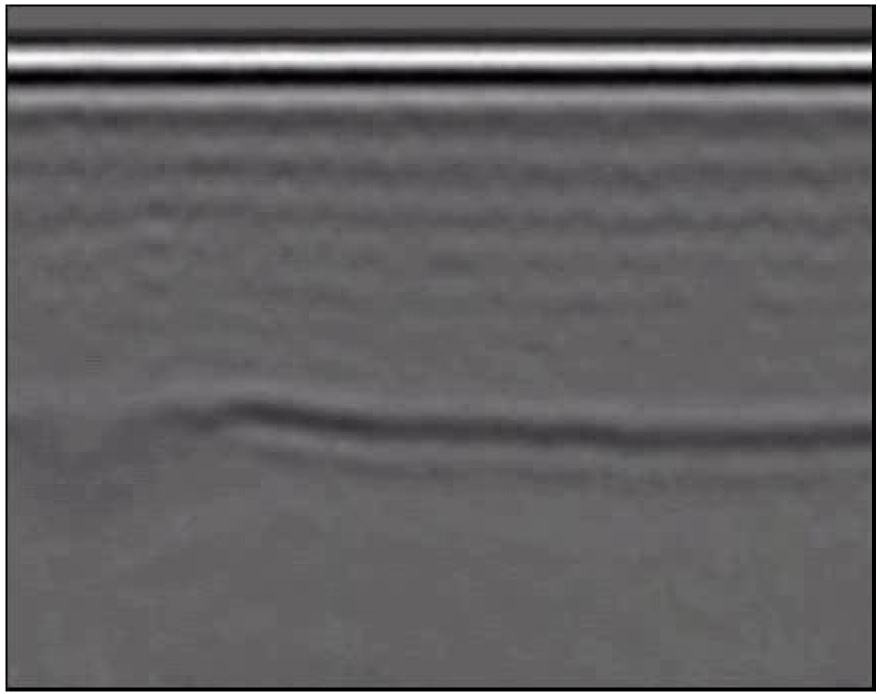
Seuls l'épaisseur et les dimensions latérales des défauts peuvent être estimés.



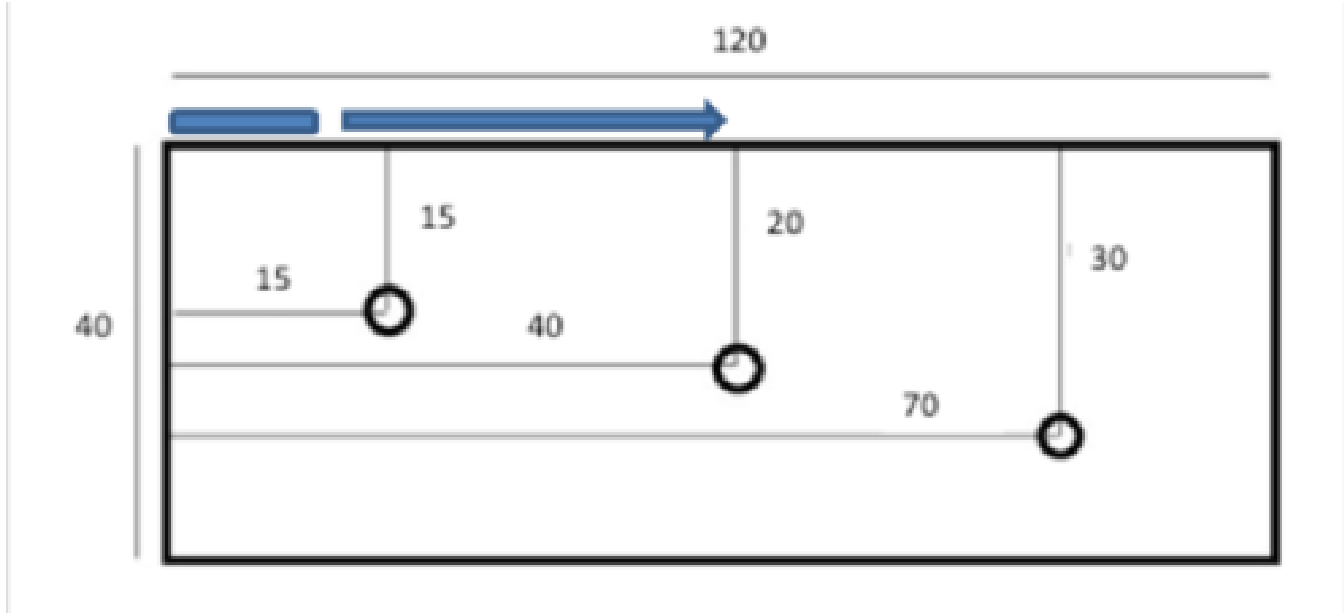


B-scan presentation

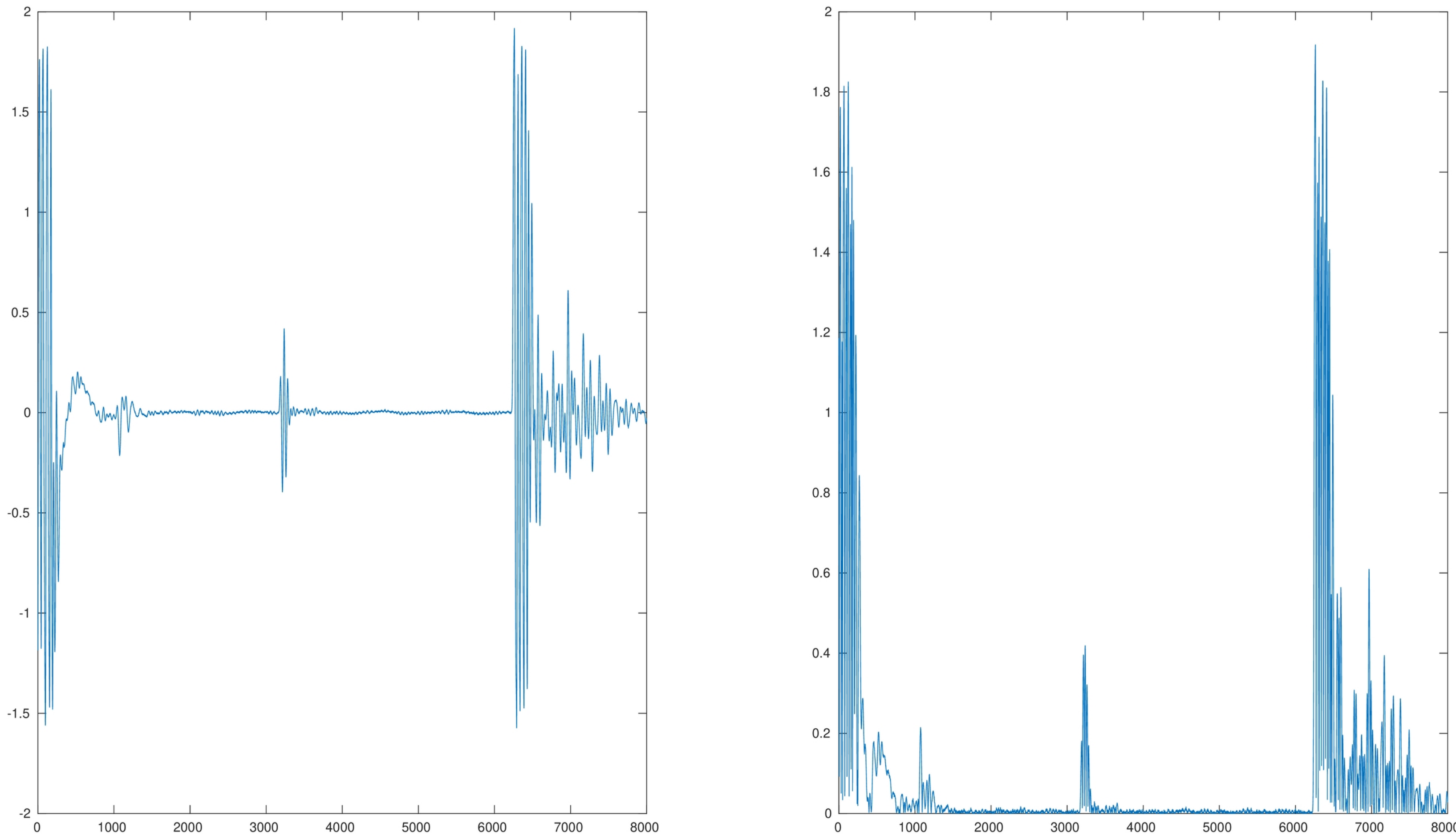




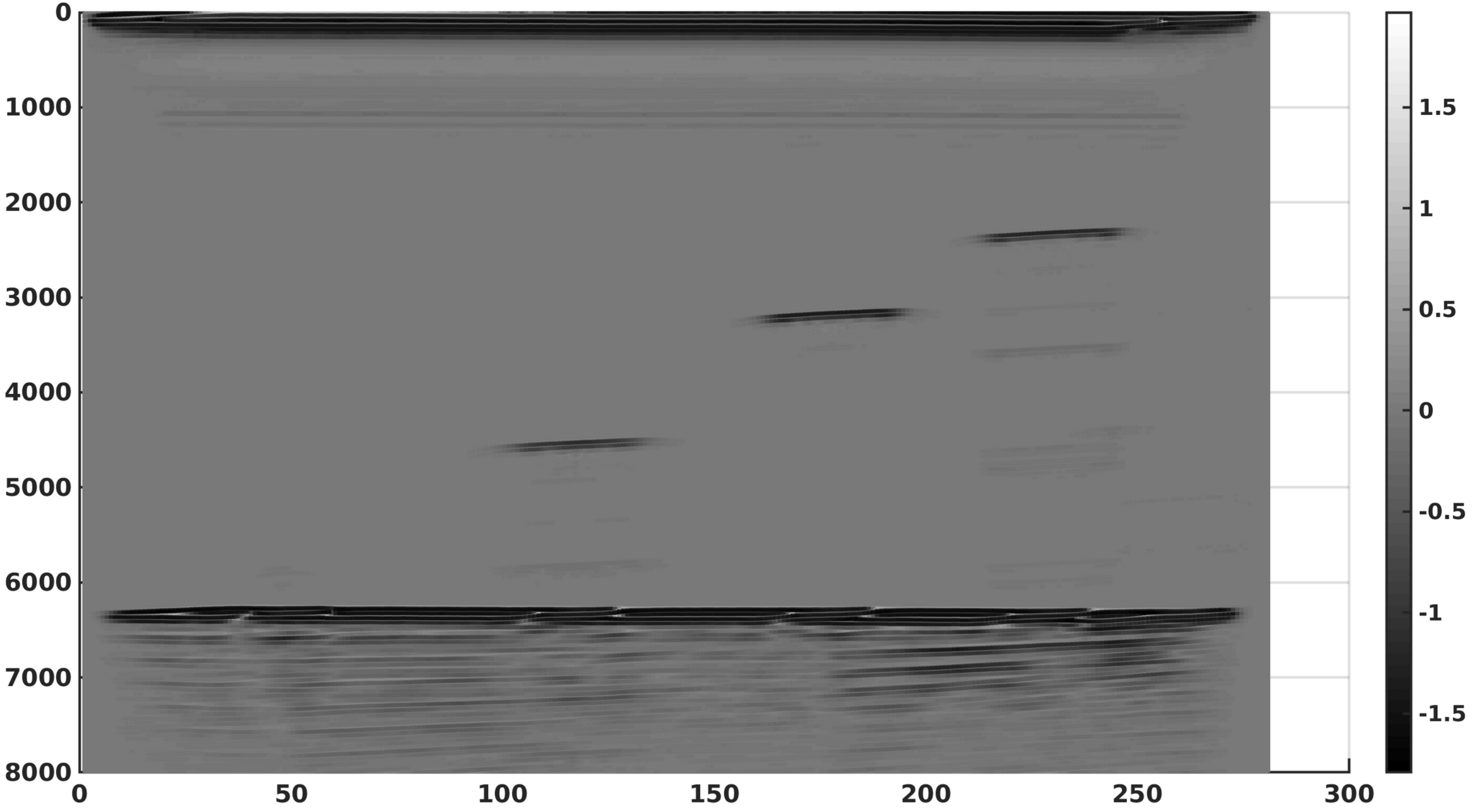
Test sample



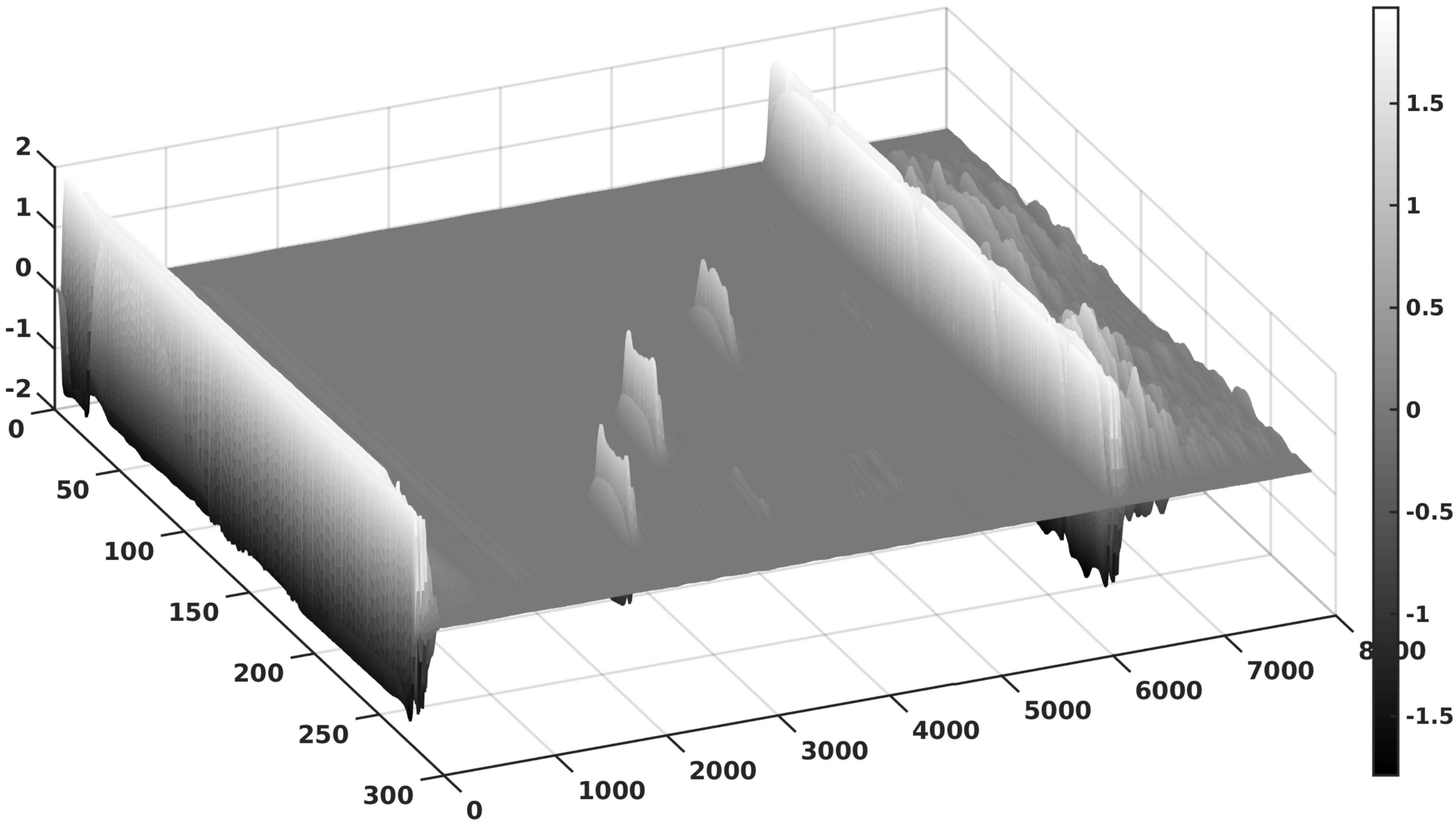
A-scan presentation



B-scan presentation

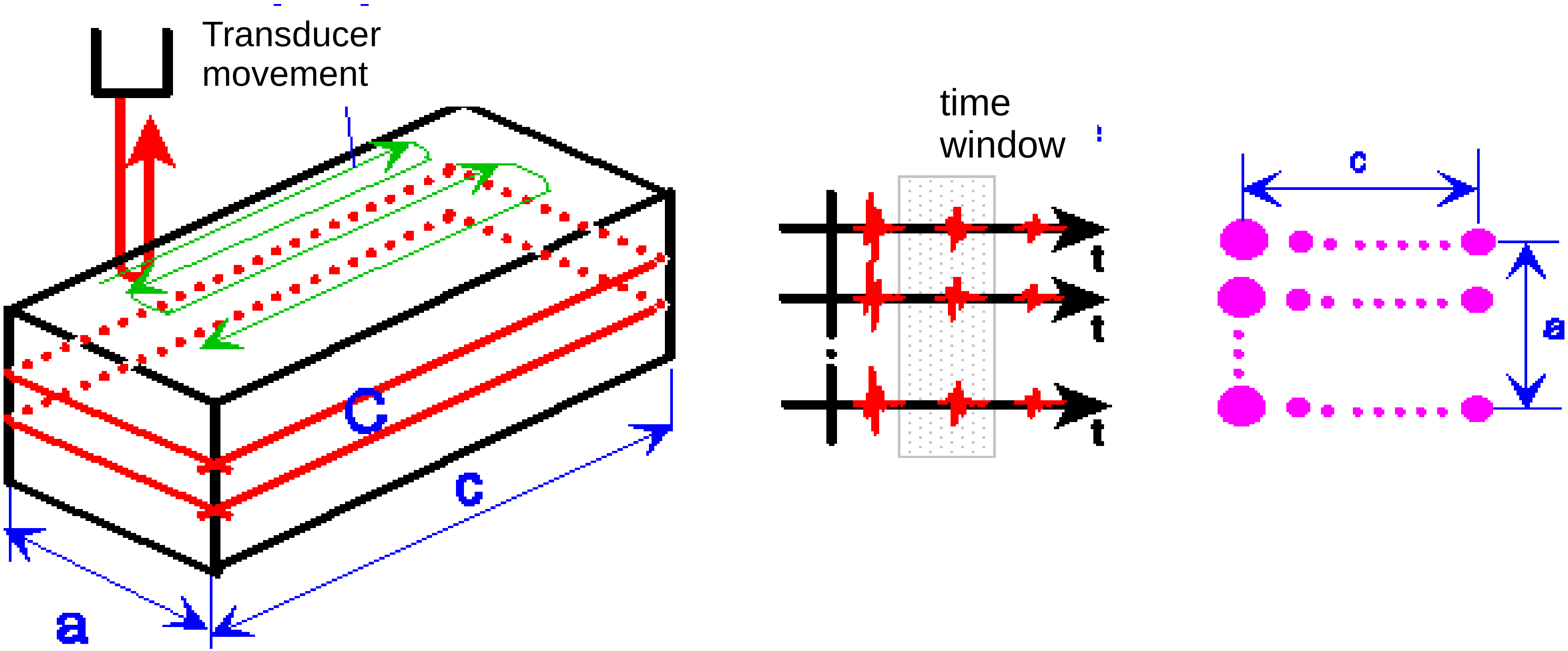


3D view of the B-Scan



C-scan presentation

The C-scan presentation is a plan-type view parallel to the scan pattern of the transducer. C-scan are produced with computer controlled scanning systems. Typically, a data collection of A-scan is recorded at regular intervals as the transducer is scanned over the test piece. The relative signal amplitude or the time-of-flight is displayed as a shade of gray or a color for each of the positions where data was recorded.



C-Scan presentation

C-Scan composite

C-scan recalé