PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

UNIVERSITY OF M'HAMED BOUGARA - BOUMERDES

Faculty of Technology

Mechanical Engineering Department

**Handbook**

Title:

# Non Destructif Test
# NDT

Realised by:

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2022

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# I. Generality on NDT

## I.1 Introduction:

Non-Destructive Testing (NDT) is a set of methods that allow to characterize the state of integrity of structures or materials, without degrading them, either during production, or during use, or during maintenance. The content of this course presents the techniques of non-destructive testing (NDT) most commonly used in industry. For each of the techniques, a presentation of the principles and methods of use is made at first. Then a more detailed approach (physical principles and basic equations) will be proposed. The presentation is also based on graphical illustrations often translating the equivalent of several pages of description and comments. This course also proposes test and evaluation activities allowing the learner to self-evaluate the mastery of the proposed content. Learning activities are also offered to learners. During these activities, the learner is called upon to deal with problems that will lead him/her to deepen the subject matter through research, analysis and synthesis. For some of these techniques, an overview is also given on the control equipment and its operation through a document of introduction to the TP. The objective of this course is to make students aware of the concept of non-destructive testing. This field is part of the general concept of quality assurance, it plays a key role in all applications requiring a minimum of safety and reliability (pipe, nuclear, aeronautics, automotive,). This course is an initiation that aims to show in a concrete way (based on practical work done on real parts) how and why these techniques are implemented.

The name Non-Destructive Testing naturally brings to mind the diagnosis that a doctor makes when examining his patient: the same principle applied to mechanical parts consists of implementing investigative methods that make it possible to judge "without destruction" the state of health of the parts and to formulate an opinion on their ability to perform the function for which they are intended.

Considered under this aspect of fitness for use, the definition supposes a good knowledge of all the phenomena involved, in particular the harmfulness of the defects, their evolution in time and the general laws of the mechanics of rupture.

In practice, the non-destructive testing specialists in charge of inspection are more confronted with problems of interpretation of the test results in relation to criteria established in conjunction with the designer of the part. In this spirit, the following definition of Non-Destructive Testing appears closer to the industrial reality: it is "to qualify, without necessarily quantifying, the state of a product, without altering its characteristics in relation to recipe standards".

In this sense, non-destructive testing (NDT) appears to be a major element of product quality control. It differs from laboratory and industrial instrumentation because the purpose is to detect heterogeneities and anomalies rather than to measure physical parameters such as the weight or dimensions of a part.

**History:**

Non-destructive testing (NDT) is a privileged field of application of the discoveries of physics. The history of non-destructive testing (NDT) began with the discovery of modern physics at the end of the 19th century: discovery of X-rays, eddy currents, piezoelectricity, etc. However, it was not until the Second World War that NDT techniques took their place in industry, particularly in metallurgy: control of steels, radiography of welds. A great development of NDT occurred in the 1960s/1970s with the rapid development of application sectors such as nuclear power plant engineering, civil aeronautics, gas and oil pipelines and off-shore platforms. The last decade has seen the emergence of NDT techniques that could not be implemented without the contribution of integrated electronics and powerful computing; we are then witnessing the rapid development of fully automated controls and the rise of techniques requiring computer processing, such as optical controls. At the same time, we find this same evolution in certain medical control techniques such as ultrasound, radiography... the basic physical principles are often similar to industrial techniques. The principle of the detection of a defect is to excite it and to collect its response. In all the methods used, we can distinguish the following steps:

- Implementation of a physical energy process,

- Modulation or alteration of this process by the defects,

- Detection of these modifications by an appropriate sensor,

- Signal processing and interpretation of the information provided.

**NDT methods: the NDT methods used are:**

1- Visual
2- Radiography (first applications of X-ray control in 1900)

3- Ultrasound (discovered in 1883 by Galton)

4- Dye penetration (practiced in 1930)

5- Magnetoscopy (principle attributed to Major W H Hoke in 1922)

6- Thermography

7- Acoustic emission

8- Eddy current

9- Oil analysis

10- Vibration analysis

## I.2 Principe:

Two groups of detection methods can be distinguished schematically:

- The methods of flow, with an excitation and a detection of the same nature and for which the defect introduces a disturbance of flow which can be noted either directly in the transmitted flow (radiography) or the rediffused flow (ultrasounds), or by an effect of proximity (coil of probe with eddy currents, magnetic leakage flow), the great majority of the processes of the nondestructive control refer to this group of methods.

- The methods for which the excitation and detection are of different natures, each one putting in play an original and specific process; the most employed excitation is the mechanical solicitation; it leads to the techniques of analysis of mechanical vibrations or micro deformations (holographic interferometry) or to a technique of provoked emission of which the most known is the acoustic emission.

- The application of each method involves three distinct elements:
- The exciter element: often characterized by electromagnetic radiation, or a vibration and a magnetic field.
- The disturbing element: defined by the part and possibly by the defect it contains.
- The revealing element: provided either by the eye or by a system of sensors translating the reaction of the part into electrical signals.

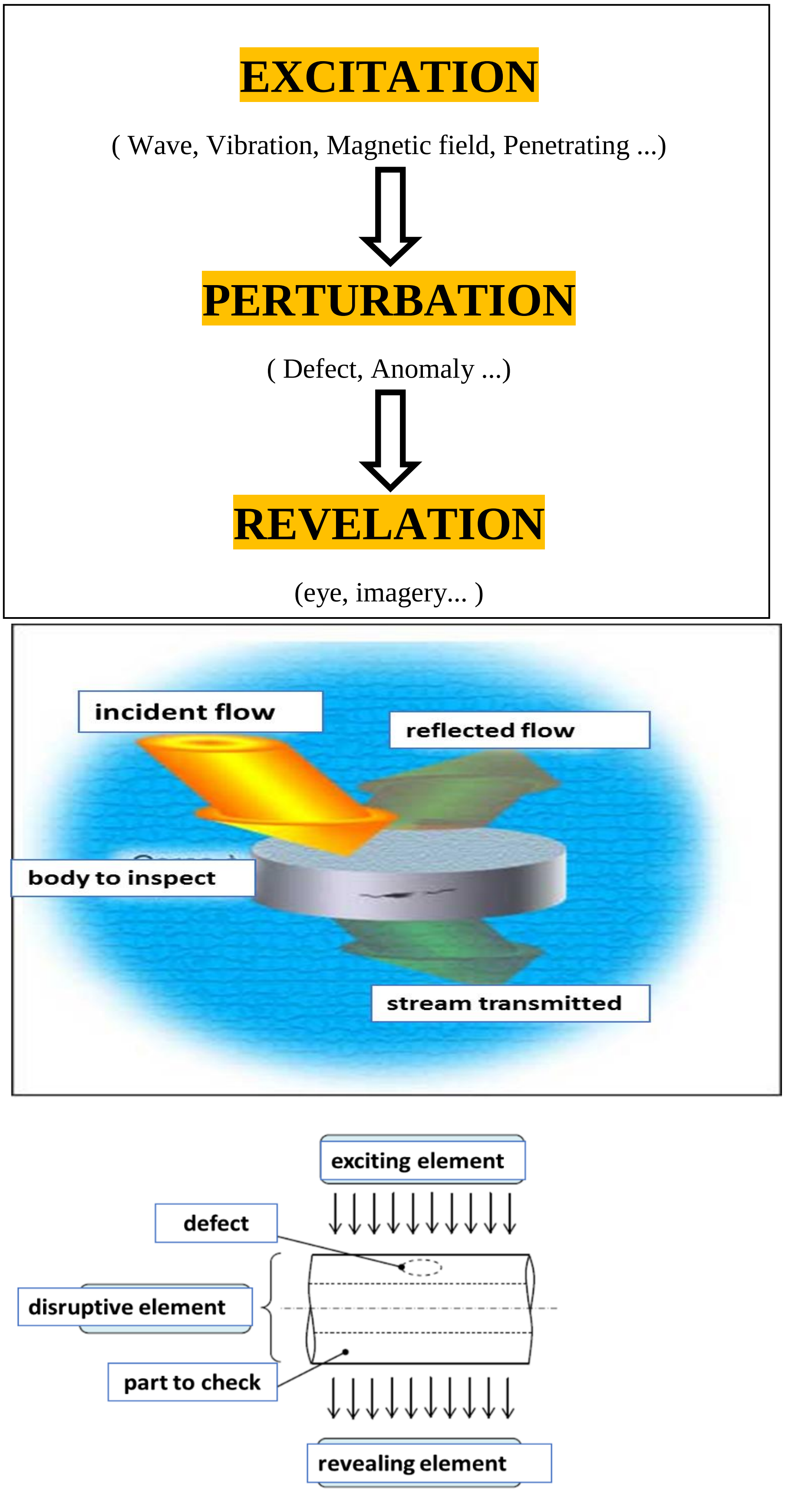



**Fig.I.1 Principle of NDT**

For each method and in accordance with the rules of quality assurance, a procedure must be put in place to ensure the reliability and reproducibility of the examination, as well as the location, identification and characterization in size and nature of the defects, their classification and presentation, and finally the decision as to the allocation of the product with archiving of the results and the conditions under which the examination was performed. This requires, in each case, the development of a procedure specifying the operations of calibration, acquisition and data processing.

## I.3 Fields of application:

Non-destructive testing is essential for manufacturing industries that implement or use different materials, products and structures of all kinds. Today, the field of application of NDT continues to expand; these techniques are even becoming essential tools in the quality approach of:

- the automotive industry (engine block control);
- the oil industry (pipelines, welds, tanks)
- the naval industry (control of hulls)
- aeronautics (aircraft wings);
- the energy industry (reactors, boilers, turbines)
- the railway industry (axles, wheels);

The nature of the defects to be detected is very variable. We are looking for specific technological defects, such as those inherent to the manufacture and use of metals (fatigue cracks), but also appearance defects (stains on a clean surface) and harmful foreign bodies (glass fragments in a food package). For a given product, we can consider that the non-destructive testing intervenes at three different stages of the life of the product:

- The control during the manufacturing process. The system used in this case is often automated this requires an equipment installed and operating in manufacturing line. In this case, we try to satisfy both the criteria of robustness, with the speed of the reaction and a low operating cost. The defects are generally well identified, the operation is automatic, leading to a detection or a sorting of the defective products. When the defect detector cannot be installed on the production line, inspection benches are used in the industry, often corresponding to large equipment in terms of size and cost.

- The control at the reception of a batch of parts, an installation or a work, allows to verify the respect of conformity with the specifications of quality defined beforehand. At this stage, it is a question of detecting defects but also very often of defining their nature and dimensions.

- The in-service inspection is performed on parts or structures during maintenance operations or following the detection of anomalies in the behavior of the material. For this type of inspection, it is necessary to be able to estimate the nature and dimensions of the defects as well as possible in order to be able to assess their seriousness; it is also necessary to have a good reproducibility of the non-destructive examinations, in order to be able to follow the evolution of the damage over time. NDT techniques will certainly continue to expand their field of application to new sectors of economic activity. It is no longer enough to detect a defect, it is also necessary to characterize and dimension it. It is also necessary to imagine non-destructive techniques and processes capable of revealing complex physical heterogeneities or irregularities in properties such as, for example, variations in the microstructure of a metal, variations in the texture or roughness of a surface, or variations in the electromagnetic properties of a strip. These objectives are often difficult to achieve, and progress is slow. The same is not true for the automation of NDT, which benefits fully from advances in information technology. The result is that, year after year, more efficient, more reliable and, above all, easier-to-use equipment is being put on the market in compliance with very strict control procedures. However, the development of NDT must take into account the cost aspect, which can slow down the development of new high-performance techniques, as is currently the case for X-ray tomography for example

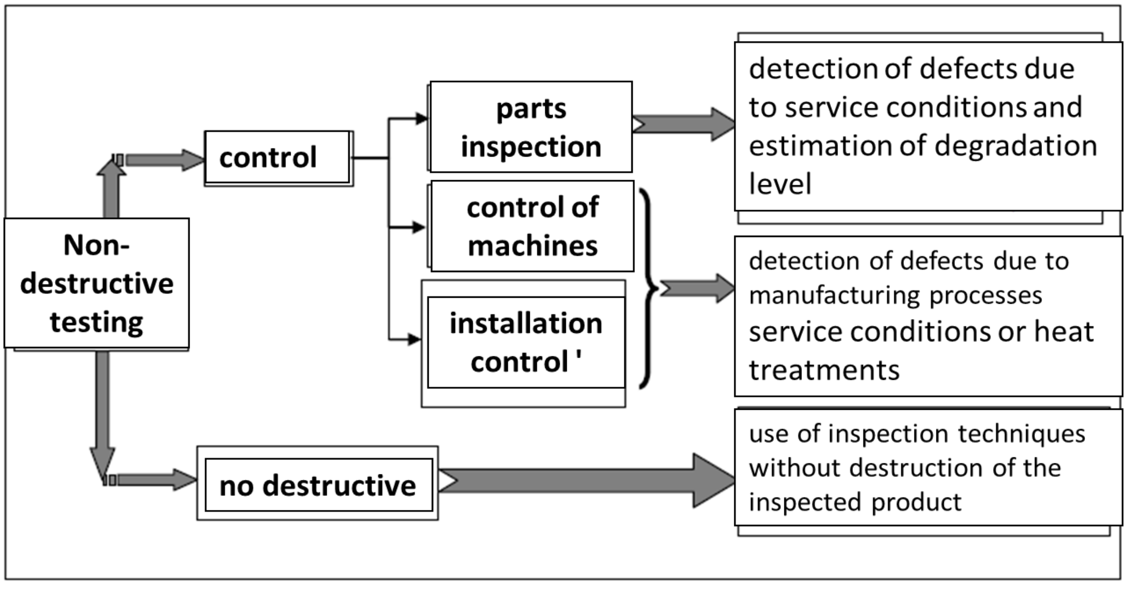



**Fig.I.2 Scope of the NDT**

## I.4 Classification of NDTs:

- External defects: Apart from the visual examination or the search for defects with a magnifying glass, we have other simple and effective methods at our disposal, such as the penetrant liquid test (dye penetrant test) or the magnetic test (magnetic particle test).

- Internal defects: The non-destructive examination of internal defects is mainly performed with X-rays and ultrasonic waves.

Basic types of non-destructive testing methods include contact and non-contact methods. Applications for testing and evaluating composites. Most NDT techniques require good contact between the sensor and the composite surface under test to obtain reliable data. Contact methods include traditional ultrasonic testing, vortex testing, magnetic testing, electromagnetic testing and dye penetrant testing. Another approach to speed up the data collection process is to eliminate the need for physical contact between the sensor and the structure under test. Non-contact methods include: transmission ultrasonics, radiographic testing, visual inspection, optical methods (thermography, holography or shearography, for example).

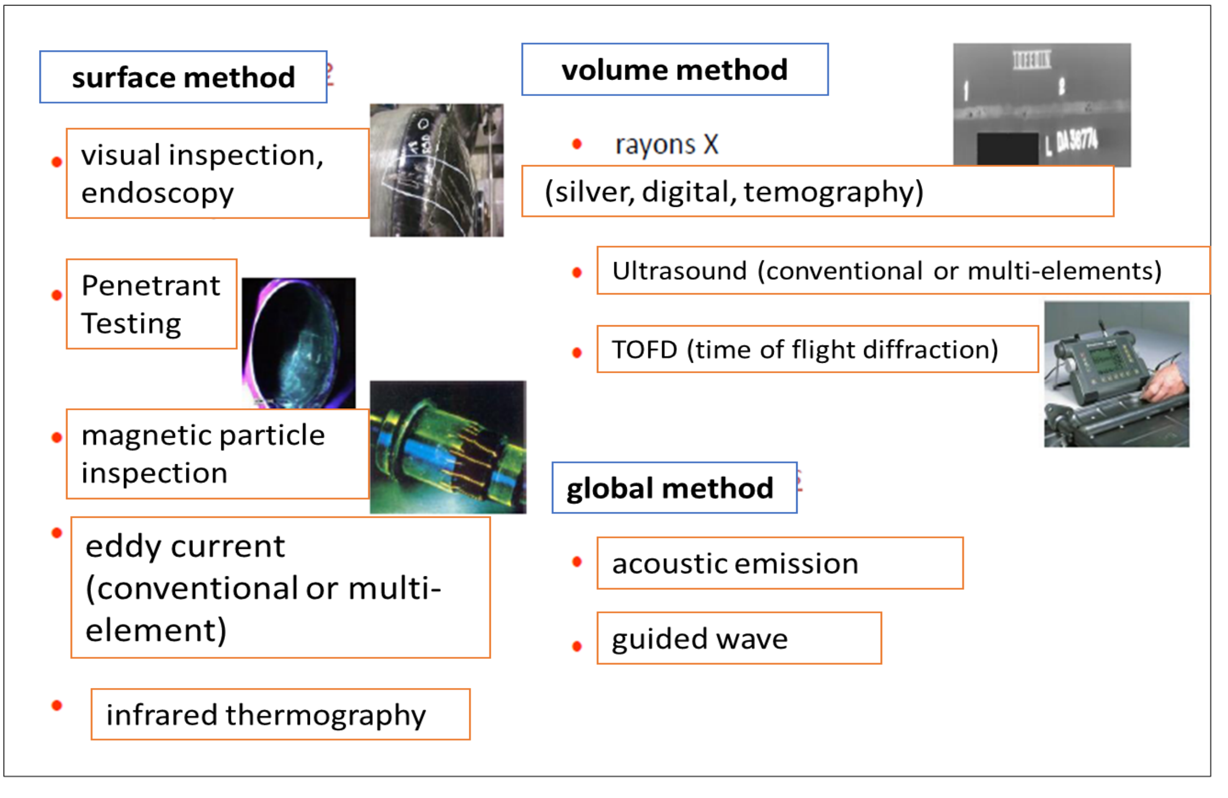



**Fig.I.3 Classification of CND methods**

The most commonly used NDT techniques can be classified into two main families, closely related to the location of the defect on the part under examination:

- Surface methods: for which the defect is located on the external surface and among them: visual examination, penetrant testing, magnetic particle inspection or eddy current.
- Volumetric methods: for which the defect is located in the volume of the part and among them: ultrasound, ionizing radiation, thermography or acoustic emission.

## I.5 The main defects in materials

When a metal or metal alloy is deformed, it first goes through a plastic deformation regime and then through a ductile damage regime. The ductility of a metallic material is characterized by its ability to deform plastically without damage or failure.

The damage represents surface or volume discontinuities. The initial causes of damage are the accumulation of dislocations in metals that modify intermolecular bonds or cause micro-decohesion's, resulting in micro-cavities or cracks.

Among the most frequent causes of failure in parts are progressive cracks caused by forces that induce significant stresses in the part. The presence of a defect that locally reduces the resolution of the part to these fatigue stresses is particularly harmful by promoting the birth of the crack.

### I.5.1 Manufacturing defects

#### I.5.1.1 Defects due to the chemical composition of the molten metal

These are essentially micro-inclusions with dimensions less than 100 µm. These inclusions generally result from reactions of the elements constituting the alloy in the liquid state with impurities such as oxygen, sulfur, and nitrogen to form:
- Oxides,
- Sulfides,
- Nitrides.

#### I.5.1.2 Defects related to the solidification process

**a/ Segregation**

This phenomenon has already been mentioned in the chapter "General metallurgy". It takes place during solidification and leads to an enrichment in impurities (sulfur in particular) of the liquid metal as the less "fusible" elements solidify. Segregation can occur at two scales:
- at the grain or dendrite scale: this is minor segregation. This can lead to hot cracking or to liquation phenomena.

- on the scale of the ingot or the piece: it is the major segregation. The last solidified parts of a piece are then made of a metal more impure than the average composition of the piece.

**b/ Reversals**

The shrinkage that occurs during solidification is the cause of shrinkage. Indeed, the passage from the liquid state to the solid-state results in a decrease in volume (about 3% for a steel with 0.35% carbon).

The design of a casting must therefore take into account this phenomenon in order to :

- to supply the shrinkage of the metal constituting the future part,
- to localize the shrinkage in the areas that will be dropped.

Feeder weights allow a better control of the solidification of a casting. However, local variations in the mass of the part (thickness variation) can lead to the formation of inter-dendritic micro-shrinkage.

**c/ The creeks**

These are intergranular cracks that develop under the action of shrinkage stresses after solidification of a part of the part. These defects, generally superficial and not very deep, appear:

- In particularly stressed areas (connection radii, interior corners),
- In segregation bands with basaltic solidification.

Some central parts are also the seat of inter-dendritic micro-cracks due to shrinkage stresses hindered by the rigidity of the solidified outer layers and possibly amplified by allotropic transformations.

### I.5.1.3 Defects related to the production process (Casting, Molding)

**a/ Blows and stings**

These are gas bubbles trapped in the metal during solidification. The gas can come from :

- From the "effervescent" character of the steel (CO),
- From the mold or a foundry core ($H2$, $H2O$, $N2$),
- Variation in the solubility of gases dissolved in the metal.

Blowholes are internal defects and are of endogenous nature (related to the quality of steel).

Pitting is a surface defect and is exogenous (from the mold or the atmosphere).

These defects can have three main configurations:

- Spheroidal, small diameter (about 1 mm), quite numerous and localized in the vicinity of the skin.

A heat treatment and sandblasting can make them unlockable.

- Ovoid and sometimes a few centimeters long, oriented perpendicular to the surface,
- Of any shape (rounded), sometimes associated with slag or pits.

**b/ Macro-inclusions**

They are differentiated from micro-inclusions by their exogenous nature and size. They are generally oxides coming from:

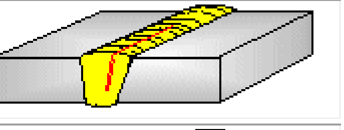
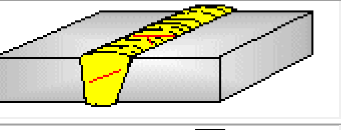
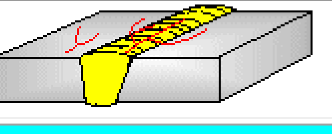
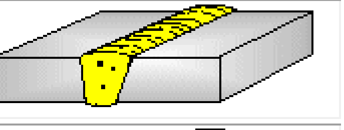
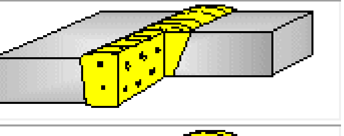
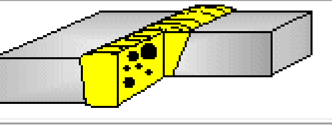
- oxidation of the liquid metal during its production (furnace, ladle, casting, mold),
- the possible entrainment of refractory lining (furnace, ladle, mold), slag or sand,
- elements added for calming.

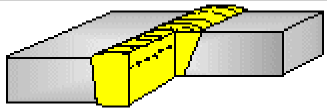
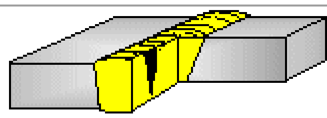
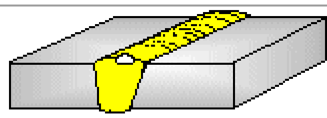
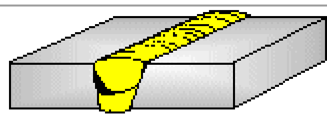
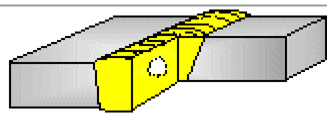
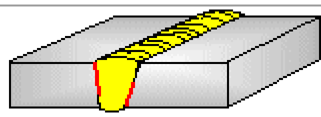
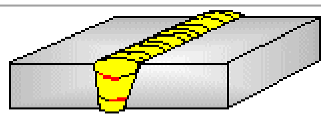
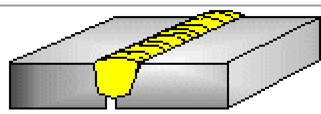
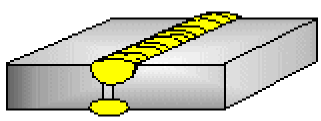
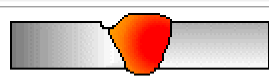
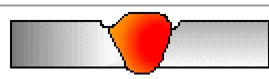
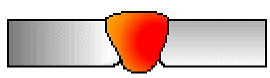
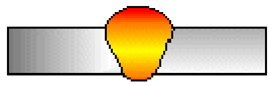
Composition: FeO, MnO, SiO2, Al2O3, CaO. Their dimensions are generally superior to the millimeter. Macro-inclusions detectable by classical CND methods...

**c/ The flakes**

These are cracks that appear during cooling, in the solid state, as a result of local stresses due to shrinkage during the allotropic transformation $\gamma \rightarrow \alpha$. Segregations, as well as hydrogen, promote the appearance of these defects by locally weakening the material. These defects are called flakes because of their characteristic appearance in the form of circular spots of 1 to 3 mm in diameter, radiating around a crack

## I.5.2 DEFECTS IN WELDED CONSTRUCTIONS

| **Table of welding defects** | | | |
|---|---|---|---|
| Number | Designation | Illustration | |
| GROUP N° 1 - Cracks | | | |
| 101 | Longitudinal cracks |  | |
| 102 | TRANSVERSE CRACK |  | |
| 103 | RADIANT CRACKS |  | |
| GROUP N° 2 - CAVITIES | | | |
| 2011 | SPHEROIDAL BLAST |  | |
| 2012 | EVENLY DISTRIBUTED BLOWINGS |  | |
| 2013 | NEST OF PUFFS |  | |

| | | | |
|---|---|---|---|
| 2014 | ALIGNED BLAST |  | |
| 2016 | VERMICULAR BUFFER |  | |
| 2017 | STING |  | |
| GROUP N° 3 - SOLID INCLUSIONS | | | |
| 301 | SLAB INCLUSION |  | |
| 304 | METAL INCLUSION |  | |
| GROUP N° 4 - LACK OF FUSION | | | |
| 4011 | LACK OF EDGE BLENDING |  | |
| 4012 | LACK OF BLENDING BETWEEN PASSES |  | |
| GROUP N° 5- MANQUE DE PÉNÉTRATION | | | |
| 402 | MANQUE DE PÉNÉTRATION |  | |
| 402 | MANQUE D'INTERPÉNÉTRATION |  | |
| GROUPE N° 5 - DÉFAUTS DE FORME | | | |
| 5011 | CANIVEAU |  | |
| 5012 | MORSURE |  | |
| 5013 | CANIVEAU A LA RACINE |  | |
| 502 | SURÉPAISSEUR EXCESSIVE |  | |

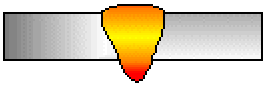
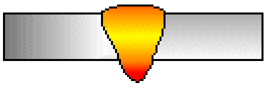
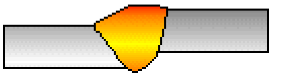
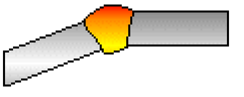
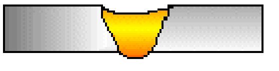
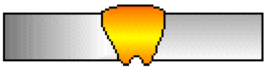
| | | | |
|---|---|---|---|
| 504 | EXCESS PENETRATION |  | |
| 5041 | DROP OR LOCAL EXCESS PENETRATION |  | |
| 507 | ALIGNMENT DEFECT |  | |
| 508 | ANGULAR DEFORMATION |  | |
| 511 | LACK OF THICKNESS |  | |
| 515 | ROOT REASSURANCE |  | |

**Fig.I.4 Types of defects**

### I.5.3 FAULTS OCCURRING DURING OPERATION

#### I.5.3.1 Fatigue defects

In case of accumulation of a certain number of cycles associated with a stress "σ" of a certain amplitude, a micro-cracking starts in one or more points of the test specimen or the part (in particular from the notches or pre-existing defects). This small crack(s) gives rise to a fatigue crack that propagates. If the cyclic loading is interrupted, the crack propagation also stops and starts again, when the loading is again applied away from the point of origin. Thus, a fatigue crack occurring in service usually presents, on the fracture face, a series of stop lines whose concavity is mostly turned towards the point of origin. The origin of the fracture and its subsequent propagation can thus be identified. The final failure does not always occur in service because it is sometimes possible to take remedial measures before this stage is reached. The important characteristic of fatigue cracking is that, when the load is maintained, it progresses with little or no deformation and may not be easily detected by visual examination.

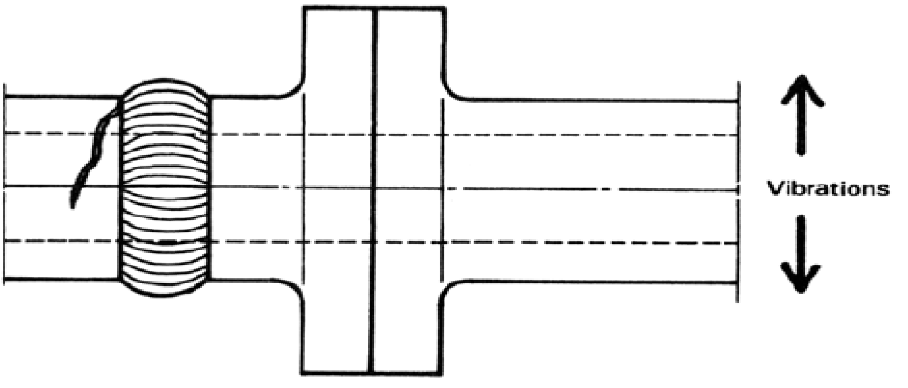



**Fig.I.5 Crack at the right of a notch effect under the effect of vibrations**

### I.5.3.2 Corrosion phenomena

**- Stress corrosion cracking**

Generally, these branched cracks are oriented perpendicular to the direction of the tensile stresses. In welded assemblies, they develop on the corrosive side and generally under stress concentration due to sheet forming, residual welding stresses or service stresses. This phenomenon appears only for certain couples of materials/corrosive media. The temperature of the corrosive environment also plays a very important role.

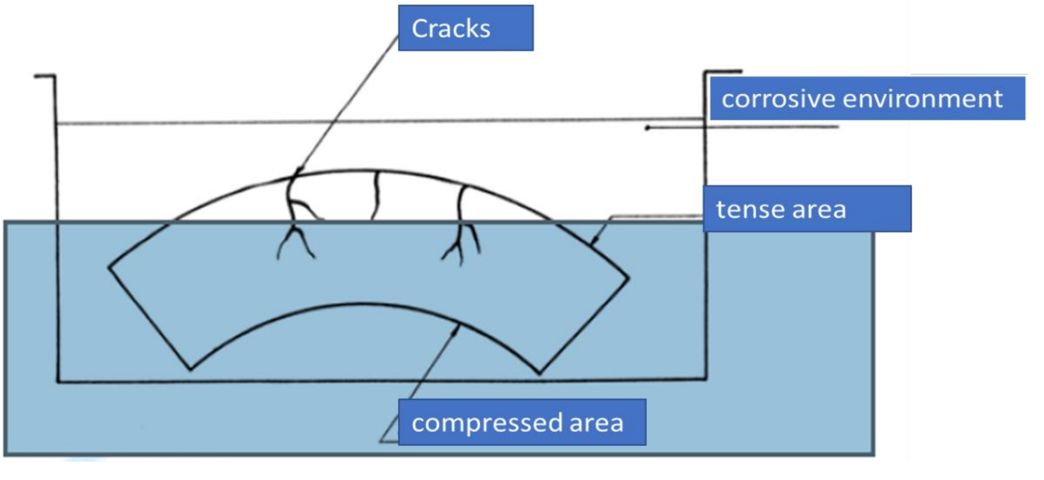



**Fig.I.6: Development of cracks in the tensioned zone of a bent part in a corrosive environment**

### I.5.4 Heterogeneities and defects

The term defect is ambiguous, relative and not very precise, but its negative connotation evokes well the role that non-destructive testing plays in the search for quality. In fact, to detect a defect in a part is physically to highlight a heterogeneity of material, a local variation of physical or chemical property detrimental to the good use of it. That said, we usually classify defects into two main categories related to their location: surface defects, internal defects.

**Surface defects**

Surface defects, accessible to direct observation but not always visible to the naked eye, can be classified into two distinct categories: point defects and appearance defects.

**a- Punctual defects** which correspond to the most harmful defects from a technological point of view, since they are cracks, pits, fissures, cracks, generally capable of causing the failure of the part in the long term, by initiating fatigue cracks for example. In metal parts, the thickness of these cracks is often very small and they can be harmful as soon as their depth exceeds a few tenths of a millimeter, which implies the use of sensitive non-destructive methods for their detection, such as dye penetrant testing, magnetic particle inspection, eddy currents, ultrasound.

**b- The defects of aspect** which correspond to areas in which a variation of geometric or physical parameters (roughness, excess thickness, various stains) attracts the eye and makes the product unusable. Here, visual control is possible, but we are trying to replace it by automatic optical controls.

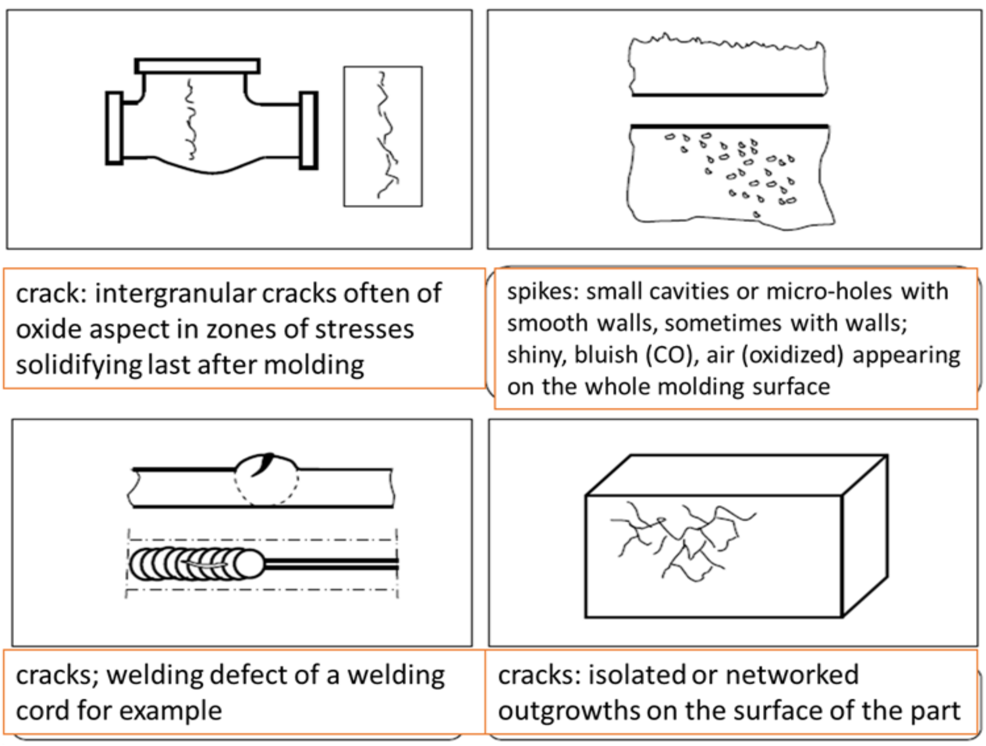



**Fig.I.7 Defects**

# II. Visual VT

# II. Visuel

## II.1 Introduction :

This is the first, simplest and most general inspection process since it is also the end point of most other non-destructive processes. As a preliminary examination, the visual inspection of an object, a structure, an assembly such as a weld will allow to guide an experienced observer in the definition of another technique: choice of the angle of shooting in radiography, direction of magnetization, ultrasonic frequency. The direct visual examination of the parts can constitute a sufficient control for the detection of the defects emerging on the surface and especially of the local and superficial heterogeneities (spots of various natures) constituting exhibitory defects of aspect for flat products of the type's sheets, fabrics, glass, etc. However, the purely visual examination presents various limitations that we will examine and that justify the development of a whole range of optical control processes. Visual inspection is an essential technique in non-destructive testing. The external condition of a part can gives essential information on the condition of the part: obvious defects (such as bends, breaks, wear, corrosion, open cracks, ...) hidden underlying defects with an irregularity on the external surface can be an indication of a more serious defect on the inside. choosing the most suitable NDT technique for in-depth examinations determine the limitations of other NDT techniques chosen (access, surface condition, etc.). Leak tests, pneumatic tests and hydraulic tests also include a visual examination to identify possible leaks.

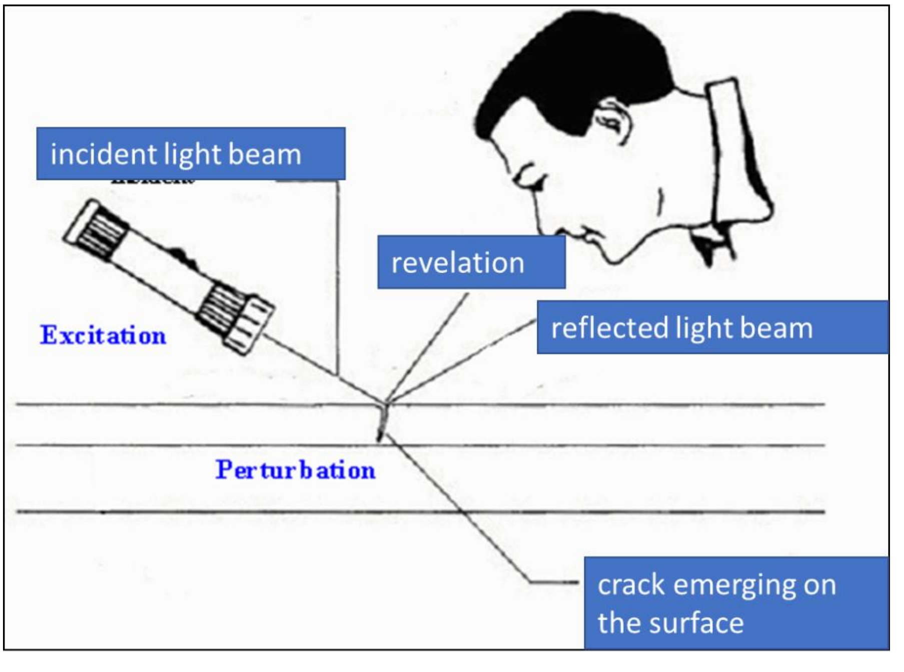



**Fig.II.1** Inspection by visual inspection (VT)

## II.2 Specific VT Objectives::

- To know the principle, the theoretical bases of visual inspection and its instrumentation

- Evoke the methods of signal processing (filtering, localization, characterization of damage mechanisms...)

- Know the industrial and laboratory applications of the technology (control of pressure vessels, corrosion detection, leak detection, examination of composite structures...)

## II.3 Principle :

Visual examination is the oldest, simplest and most general inspection process. The visual examination is also used in the final stage of several other non-destructive testing processes. The direct visual examination of the parts can constitute a sufficient control for the detection of the defects emerging on the surface and especially of the local and superficial heterogeneities (spots of various natures) constituting redhibitory defects of aspect for flat products of the type sheets, fabrics, glass, etc. However, the purely visual examination has its limits at different levels. This justifies the emergence of a whole range of optical control processes, the main ones being described below.

In all situations of examination of an object, the lighting conditions are essential for the reliability of the optical control. It is first of all a question of placing oneself in conditions of energy, luminosity and wavelength allowing the eye to work with the best acuity. An illumination of more than 300 lux in green-yellow light at 0.55 mm is optimal. It is also necessary to adapt the type and orientation of the lighting to the nature of the defects in order to improve the contrast. Diffuse lighting, provided for example by a set of light sources placed behind a frosted screen, is used in the search for various defects, without defined orientation. To easily detect defects such as scratches oriented in the same direction, the use of directional lighting associated with an observation of the surface under an angle close to that of the specular reflection is preferred (figure below). Defects with a certain relief are generally well highlighted by grazing lighting.

It should be remembered, however, that the natural tools of this technique (the eye and the brain) are very sensitive to various factors difficult to quantify and list such as those of a psychological or physiological nature. The quality of observation of the eye deteriorates with age, it is very sensitive to the state of mind and experience of the observer, it remains limited in terms of the size of the defect and makes the control of moving objects problematic. The use of optical aids to vision such as a binocular magnifier, a microscope, an endoscope, a microscope, television, gives visual control a new dimension. These techniques, currently benefit from digital means of acquisition and image processing, which give them much more speed, efficiency and reliability. These techniques fully exploit the modern means of computing and artificial intelligence.

## II.4 Field of application:

The field of application concerned by this fast evolution is that of the industrial control in line, that it is about the control of the products manufactured in continuous such as the strips of sheet, paper, glass, plastic or the control of parts manufactured in great series, for which one is interested not only in the absence of defect of surface but also in that of defects of aspect or dimensional irregularities (control of roofing tiles, boxes, moulded, forged, machined parts). Independently of the manufacturing control, the visual optical control, direct, by endoscope or relayed by a television equipment is of current practice in the operations of maintenance such as one carries out them in the fields of aeronautics, nuclear or chemical engineering, and in the civil engineering. Optical inspection is the final step in inspection processes described elsewhere, such as penetrant testing or magnetic particle inspection, whose role is none other than to improve the optical readability of small defects. It is also useful to remember that the main techniques of non-destructive testing deliver images that will have to be read and eventually processed: this is the case for radiography or thermography, but the mapping of defects is gradually becoming an important element of ultrasonic or eddy current testing.

## II.5 Equipment for visual inspection

-The baroscope or / fiberscope is a device that allows to see in extremely small and difficult to access places.

- Endoscopy is a method of exploration and industrial (or medical) imaging that allows to visualize the interior of ducts or cavities inaccessible to the eye.


**Fig.II.2 Endoscope Rigide modulaire**

**Fig.II.3 Endoscopes avec leurs sources de lumière**

**Fig.II.4 Micro - fibroscopie**

(Set of 3000 optical fibers integrated in a diameter of 8 mm max)

# III. RT Penetrant Testing

# III. RT Penetrant Testing

## III.1 Introduction :

Like visual inspection, penetrant testing is used to detect defects that emerge on the surface of a part or assembly by probing.

-Penetrant testing is a term that refers to the extraction of a fluid from a discontinuity in which it had previously accumulated during an impregnation operation. The impregnation of a crack by a liquid, taking advantage of its tension-superficial properties, leads, by means of a penetrant test before visual observation, to a means of searching for surface defects which is among the oldest, simplest and most used today.

It is a method designed to reveal the presence of open discontinuities on the surface of metallic parts, mainly, but also ceramic parts. This method is very simple to implement and is sensitive to open discontinuities. Discontinuities of 1 µm opening, 100 times finer than a hair, can be revealed. On the other hand, it cannot be automated and the results remain at the discretion of the operator. Moreover, it requires the use of non-recoverable products, even contaminated after use (e.g.: nuclear power plant: we are trying to reduce the volume of waste), but this method is irreplaceable for highlighting open-ended discontinuities, regardless of their location, regardless of their orientation.

## III.2 Principle

Like visual examination, penetrant inspection is used to detect defects that emerge on the surface of a part or an assembly by welding, brazing or soldering. Penetrant testing is a term that designates the extraction of a fluid from a discontinuity in which it had previously accumulated during an impregnation operation. The impregnation of a crack by a liquid, taking advantage of its tensio-superficial properties, leads, by means of penetrant testing before visual observation, to a means of searching for surface defects which is among the oldest, simplest and most used nowadays.

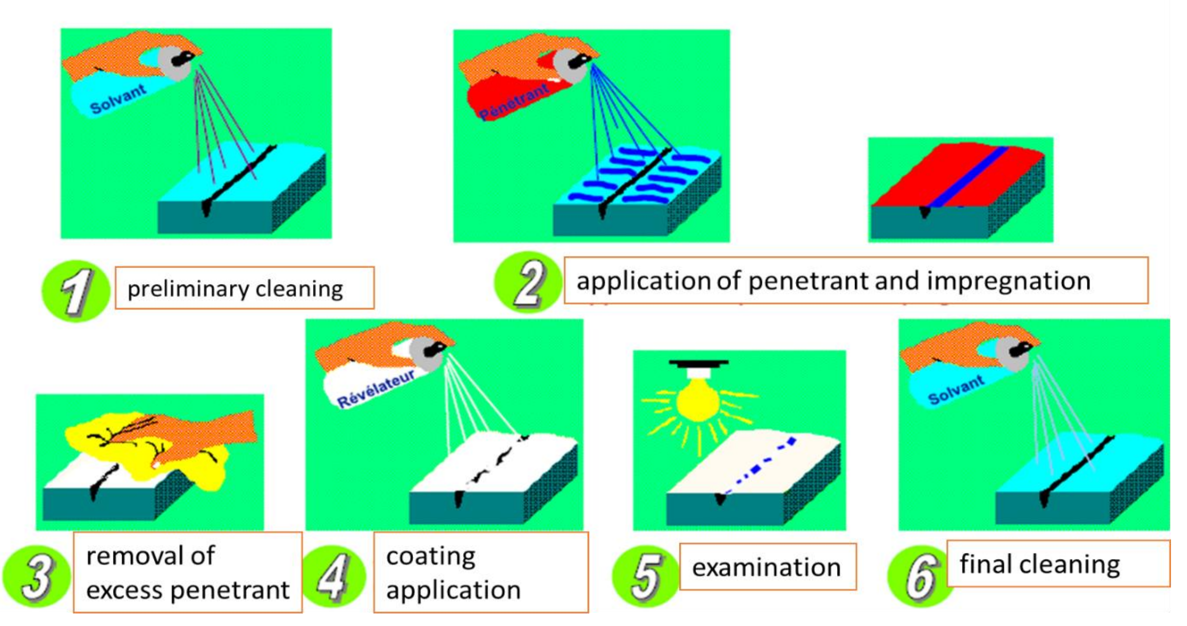



**Fig.III.1 Principle of Penetrant Testing**

**1.1. Necessary elements for handling**

**1.2.** Two families of developer ::

- Dry (powder) or non-aqueous liquid
  - Rough surface
  - Parts with complex shapes: threading, groove...
  - Large part

- **Wet** : water-based or water-soluble liquid
  - Smooth and polished surface
  - Large number of small parts
  - For the search of wide and shallow discontinuities

- **Penetrators:** are classified according to the American MIL specification; fluorescent penetrants, whether they are post emulsion or directly washable with water, are more sensitive than colored penetrants.
- **Emulsifiers:** for a long time lipophilic based on petroleum solvents, can now be supplied in the form of hydrophilic emulsifiers to be diluted in water, thus allowing a better adjustment of the control sensitivity.
- **Revealers:** are either dry or wet, suspended in water or with volatile organic carrier. The choice to be made depends on the type of control; in particular, a non-aqueous developer

is always used in association with a colored penetrant; these are by far the most used developers. Finally, there are film developers that allow to keep track of defects.

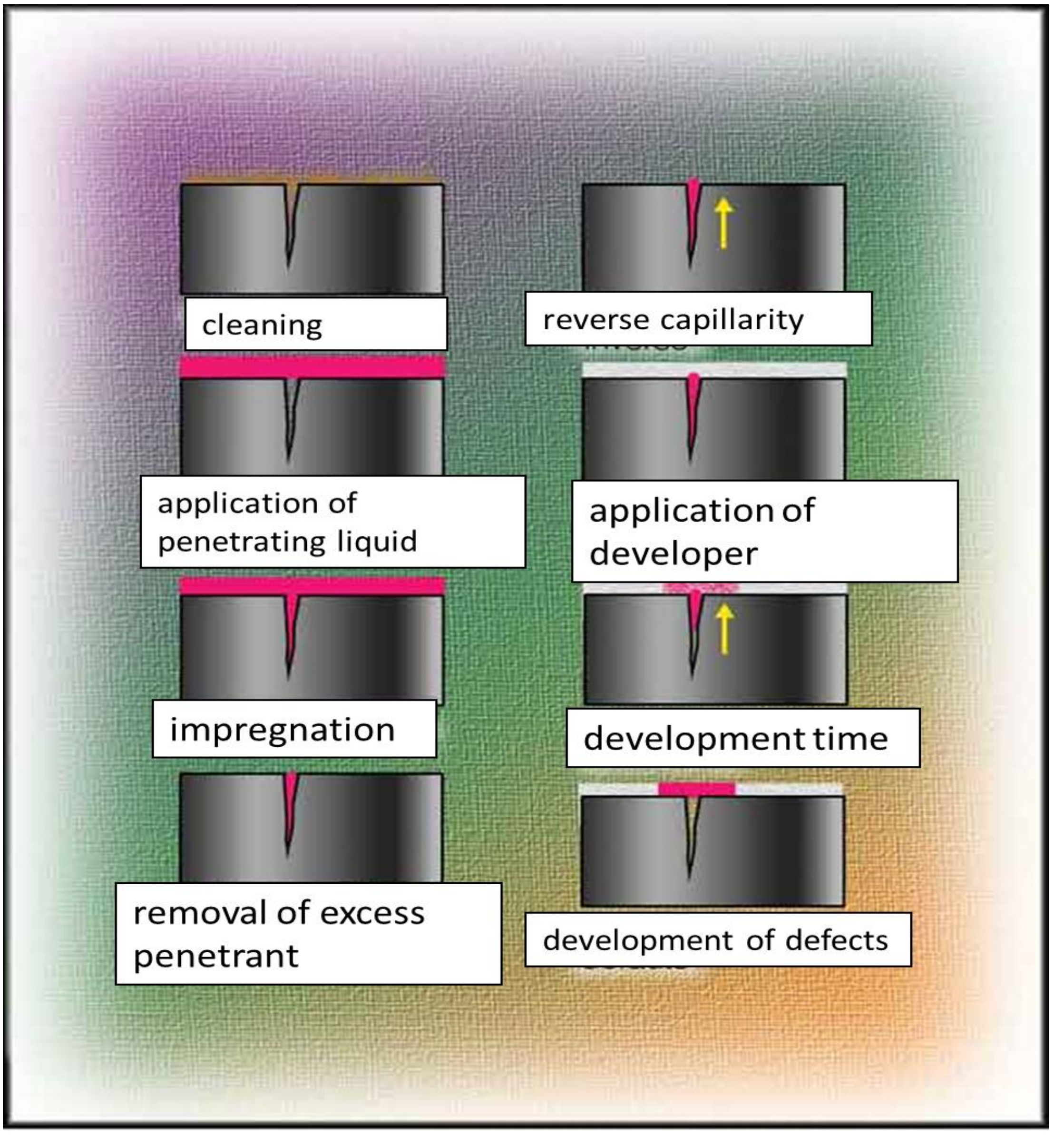



**Fig.III.2** Phases of Penetrant Testing

In any case, the mechanism of penetrant inspection corresponds to the three phases illustrated on the figure: application of the penetrant followed by an impregnation time, removal of the excess of penetrant on the surface of the part, penetrant inspection by placing a layer of "developer" on the surface. Then, the image of the defects will appear to the observer as far as the spread of the penetrant on the developer leads to a clear variation of color or luminance.

It must be remembered that, in all cases, the operations are relatively slow, taking several minutes each, from 3 to 30 minutes for the impregnation of the cracks by the penetrant. These different variants are codified in the international standards and the NF A 09-120 standard.

The illustration above shows the sequence of operations in each of the processes, knowing that the actual inspection must be preceded and followed by an extremely careful cleaning operation of the part.

There are essentially two penetrant tracing techniques used in Penetrant Testing: color tracing or fluorescent tracing; the first one implies the use of a white background developer on which one will visualize defect imprints generally colored in red; the second one implies an examination done in black light, in the dark, during which defects will be revealed by a fluorescence excited by an ultraviolet (UV) light projector. This second type of procedure almost always leads to better detection performances than those obtained with the use of colored tracers, at the price however of more constraining optical examination conditions.

The elimination of the excess penetrant is undoubtedly the essential operation in Penetrant Testing, because the reliability of the result will largely depend on the good execution of this step: a too strong washing action will risk emptying the cracks of their penetrant before it is revealed; an insufficient action will risk leaving some penetrant on the surface, in particular if it is rough, leading at the same time to wrong indications during the examination. This elimination of the excess penetrant is done by emulsification and according to two techniques, depending on whether the emulsifying agent is originally incorporated in the penetrating liquid or whether it is sprayed on the part before washing; in this case a so-called post-emulsifying penetrant is used. In some particular cases, the processes described above cannot be used properly, or the current products are not suitable for the conditions of control or the nature of the parts to be controlled. We have thus developed products adapted to the following cases low temperature penetrant testing (below about 10°C) hot penetrant testing (from 40 or 50°C up to about 200°C), corresponding to conditions encountered in multi-pass welding inspection and in maintenance of thermal installations, penetrant testing with thixotropic products for delicate "in situ" inspections (aviation), Penetrant testing with aqueous penetrants for concrete, ceramic and composite testing, and finally penetrant testing with biodegradable products which, in addition to their harmlessness towards the environment, can withstand a prolonged washing with water leading to a better reliability of the excess penetrant removal operation.

## III.3 Penetrant testing products

Penetrant products are made up of penetrants, emulsifiers and developers. Penetrants are classified according to the American specification MIL 1 25135 revision C; fluorescent penetrants, whether post emulsion or directly washable with water, are more sensitive than colored penetrants.

Emulsifiers, for a long time of lipophilic type based on petroleum solvents, can now be supplied in the form of hydrophilic emulsifiers to be diluted in water, thus allowing a better adjustment of the control sensitivity.

The developers are either dry or wet, suspended in water or with a volatile organic carrier. The choice to be made depends on the type of control; in particular, a non-aqueous developer is always used in association with a colored penetrant; these are by far the most used developers. Finally, there are film developers that allow to keep track of defects.

All these penetrant testers are sold in various forms of packaging and, in particular, in aerosol containers for unit and on-site testing; they are formulated to meet certain specifications, so as to contain only very low levels of impurities such as chlorine, sulfur, fluorine, sodium and potassium.

## III.4 Application

Both simple and delicate to implement, PT can be applied to all materials except those with a naturally porous structure and it can be considered as a global control method. It is therefore, in spite of its limitations, of great interest.

The choice of the process depends on the nature of the part and the nature of the defects sought: the colored process will be used preferably for the search of coarse defects and for the controls on site; the fluorescent process will be used when one seeks a great sensitivity and when one carries out a work in series, in particular on chain. The field of application of Penetrant Testing is very wide, because the process is easy to use and allows to detect most surface defects on non-porous metallic materials, as well as on other materials, provided that they do not react chemically or physically (adsorption) with the penetrant. Its sensitivity is very good, since one can estimate to obtain, as an indication, a reliable detection of defects of 80 mm width for 200 mm depth for dye penetrant testing performed in a workshop on a machined surface, whereas fluorescent penetrant testing leads in the same conditions to a detection limit of about 1 mm width for 20 to 30 mm depth.

The limitations of Penetrant Testing are related to the material itself: too much surface roughness, impossibility to use classical products that would damage its surface. Non-through defects cannot be seen, as well as cracks containing bodies likely to prevent the penetrant from entering such as paint, oxides, lubrication products poorly removed by cleaning. The process itself is relatively slow (10 to 45 minutes), costly in terms of time and personnel, not easy to make fully automatic, in particular at the level of the elimination of the visual examination which thus remains dependent on the acuity and the aptitude of the controller. Finally, one must take into account, in the cost of the inspection, the consumption of penetrant testing products whose use can also lead to constraining constraints with regard to the environment, safety and health at work (precautions concerning the risks of fire, explosion, irritation of mucous membranes, water pollution).

## III.4 Illustration TP

**penetrant Products: Cleaner; Penetrant; Developer**


**Step 1: Cleaning the surface to be tested with the cleaner**.

**Step 2: Drying**

**Step 3: Application of the penetrant**

**Etape 4: Step 4: After a pause, remove excess penetrant with a moderate pressure jet**

**Step 5: Application of the developer**

**Step 6: After a pause, the image of the defects appears on the surface.**

**Step 7: Final cleaning of the room**

# IV. Magnetoscopy MT

# IV. Magnetoscopy MT

## IV.1 Introduction:

The theory of magnetic circuits indicates that the presence of an air gap corresponds to a strong local increase in the reluctance of the circuit and therefore the magnetic potential difference (m.p.d.), thus constituting an obstacle to the magnetic flux whose lines of force must then spread laterally according to a leakage flux as shown in the figure opposite. This effect of dispersion of the lines of flux is exerted even for a minimal air gap, insofar as the ratio of the reluctances between the air gap and the circuit is inversely proportional to the relative permeability of the latter, i.e. a ratio of 600 to 1000 for a ferromagnetic steel circuit excited below saturation. This effect of dispersion of a magnetic flux out of a ferromagnetic part, at the right of an open crack or under the skin (or any other non-ferromagnetic heterogeneity behaving like an air gap), is at the basis of a range of magnetic processes for the detection of surface defects in steels of which the best known and the most used is the magnetic particle inspection. These magnetic processes differ from each other mainly by the way the magnetic leakage flux corresponding to the described flux dispersion is detected

Magnetic particle inspection is a non-destructive testing technique that consists in creating an intense magnetic flux inside a ferromagnetic material. When a defect is present on its path, the magnetic flux is deviated and creates a leakage which, by attracting the particles (colored or fluorescent) of a developer, provides a particular signature characteristic of the defect

## IV.2 Principle

The theory of magnetic circuits indicates that the presence of an air gap corresponds to a strong local increase in the magnetic potential difference (MPD), thus constituting an obstacle to the magnetic flux whose lines of force must then spread out laterally according to a leakage flux as shown in the figure opposite. This effect of dispersion of a magnetic flux out of a ferromagnetic part, at the right of an open crack or under skin (or any other non ferromagnetic heterogeneity behaving like an air gap), is at the base of a range of magnetic processes of detection of the surface defects in steels, of which the most known and the most used is the magnetic particle inspection. In MT, an accumulation of iron powder or colored magnetite caused by the leakage flux is visually observed.

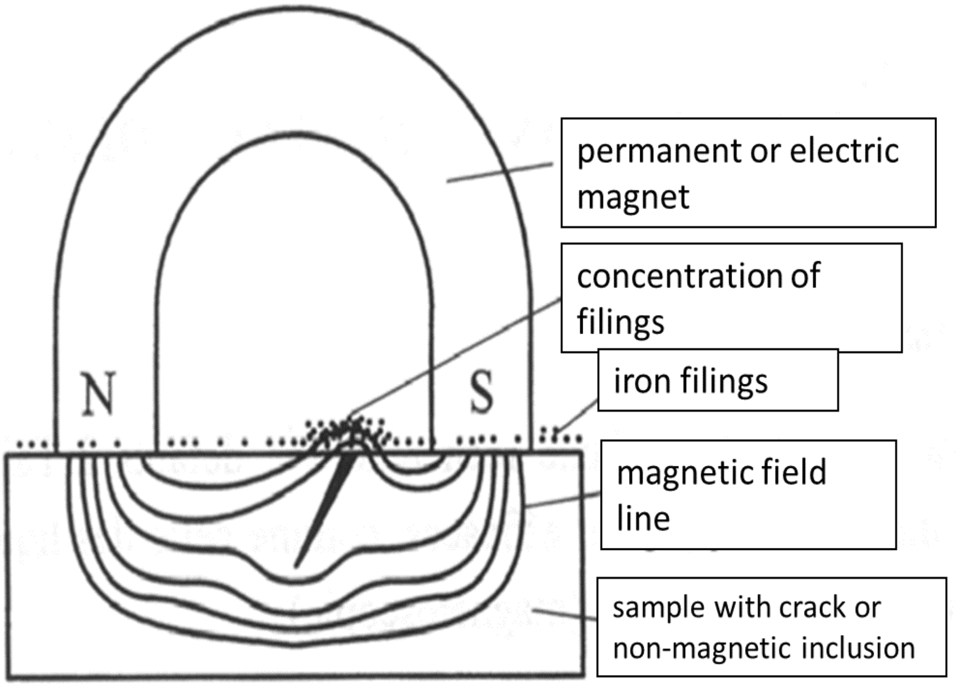



**Fig. IV.1 principle of the magnetic particle method**

The first thing to note is that the magnetic field to be considered is the one exerted in the vicinity and on the surface of the part; it must be perpendicular to the presumed direction of the cracks sought, otherwise the air gap effect will be minimized, and even cancelled out if the directions are parallel. The visual detection of magnetic leakage fields in the vicinity of defects can be done by observing the accumulation of iron filings due to flux concentrations on the surface of the part to be tested. In practice, specially adapted magnetic developers are used, consisting of a ferromagnetic powder with a well-defined particle size, often combined with coloring tracers that usually fluoresce under black light. The products, which must be evenly distributed on the surface of the part during magnetization, are either in the form of dry powder or, much more frequently, in the form of a magnetic ink. The most commonly used liquid carrier is petroleum; however, its use involves certain risks (fire, allergy, odor, storage).

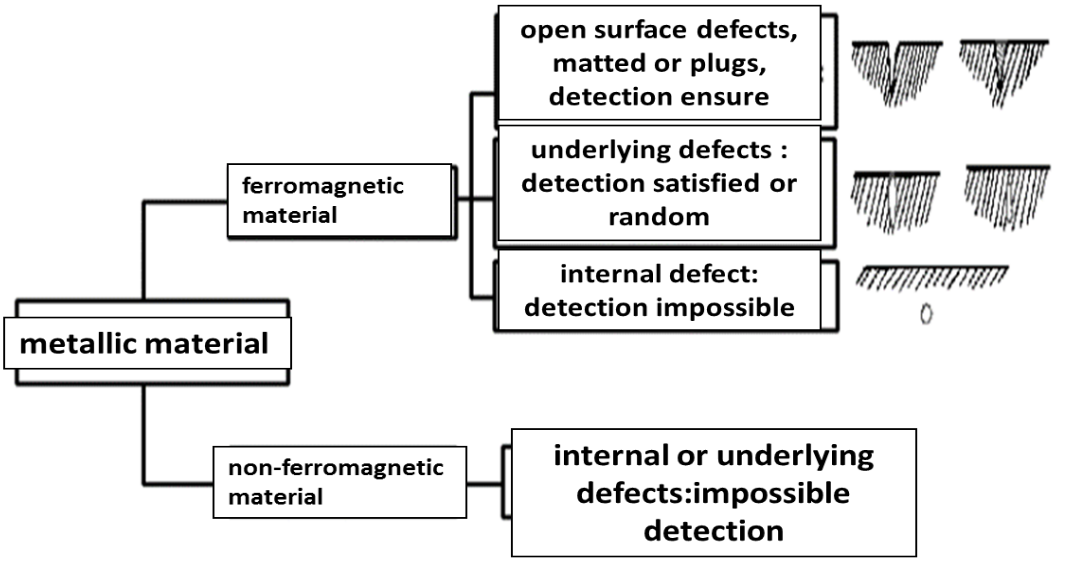



**Fig. IV.2 : Field of application of magnetic particle inspection**

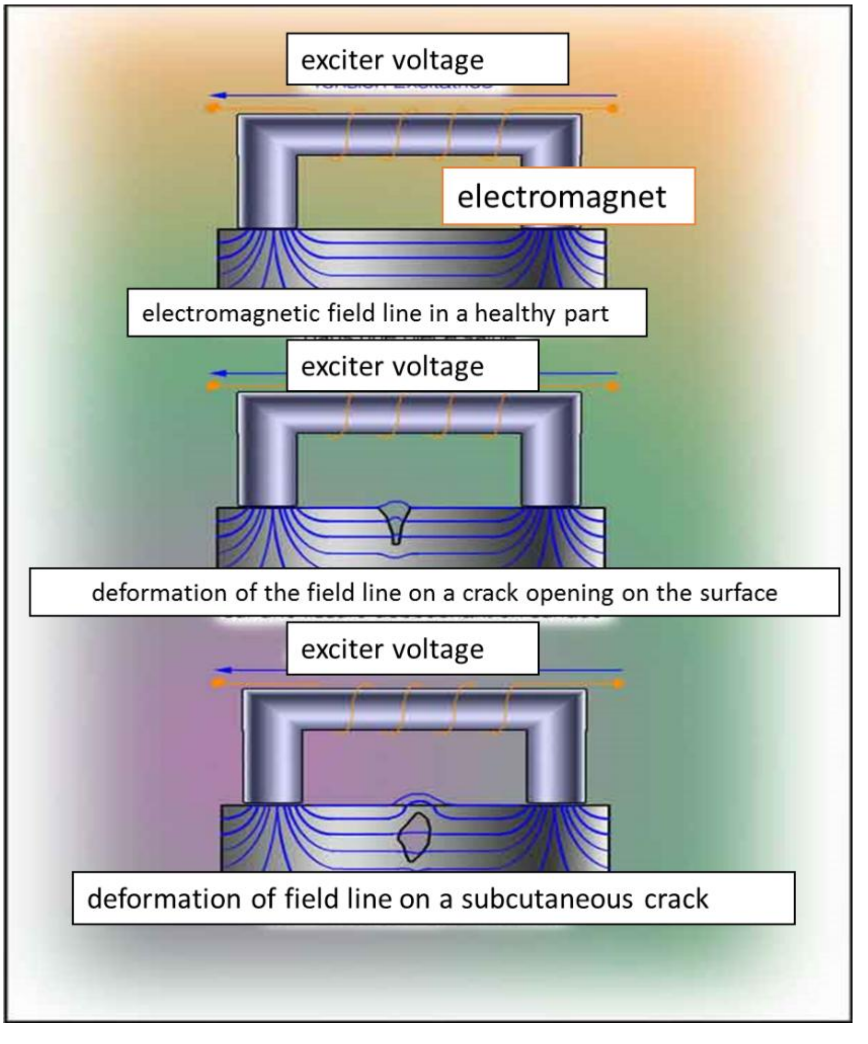



**Fig.IV.3 Principle of Magnetoscopy**

## 1.1. Necessary elements for handling

ESX 220 articulated arm electromagnet: This device, delivered in a case, has articulated arms with laminations, the lower part of the poles of which can be removed, thus allowing the height of the VTR to be lowered to 130 mm. Due to its design, this VCR can work on parts with complex geometry. Moreover, it is easy to hold, which guarantees an easy and efficient use.

**Fig.IV.4: The magnetizing device**


**Fig.IV.5 indicator, witness and projector**

-Remanent magnetization indicator

-Berthold indicator

-U.V. lamp: Stand-alone lamp with separate Wood filter and 100 W U.V-A lamp –

**Aerosol products:** there are two main families

Dry developers: powder (black, red, grey, blue)

Liquid developers :

Colored (black on white background, yellow,..)

Fluorescent


**Fig.IV.6: Example of liquid aerosol products**

## 1.2. Magnetic particle examination

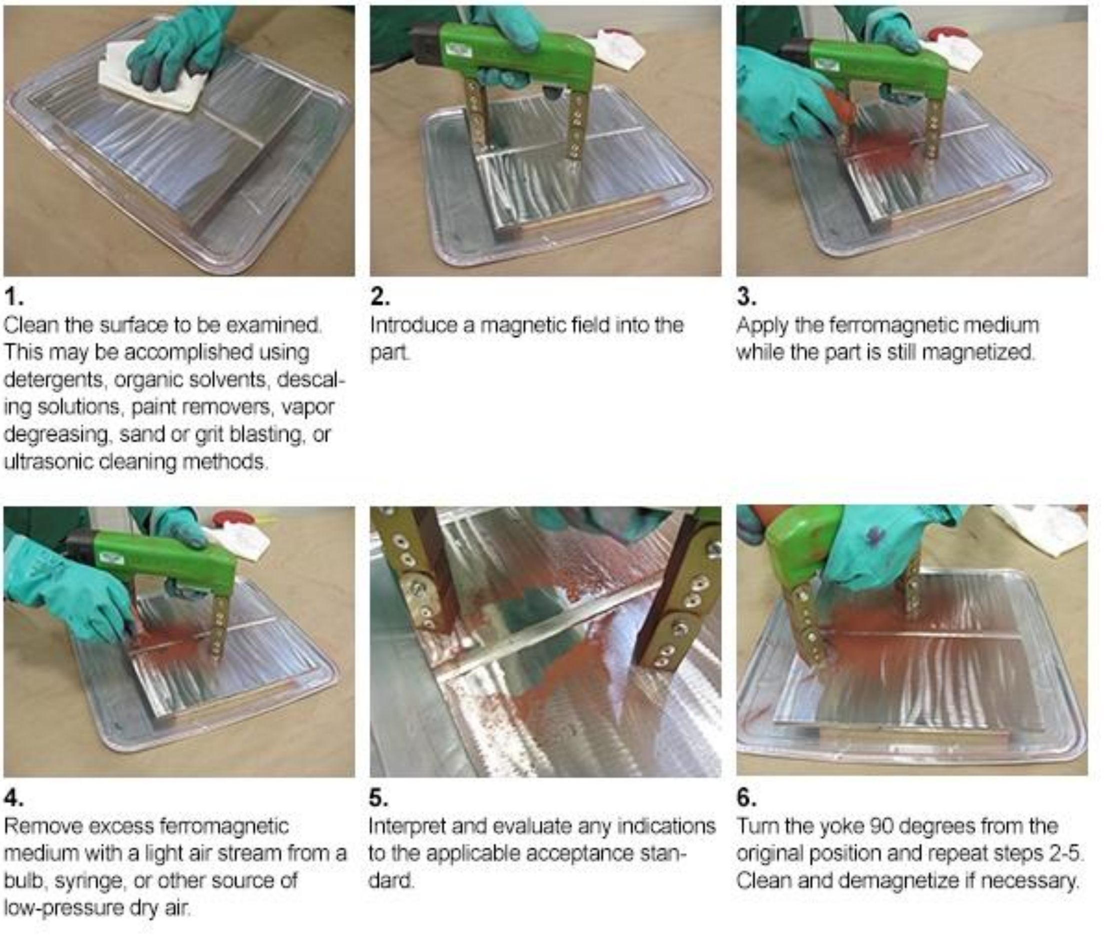



**Fig.IV.7: Magnetic particle examination**

## 1.3. Demagnetization

The principle of demagnetization consists in subjecting a material to a constantly decreasing inverse magnetic field. The residual field strength is thus reduced to a low value. It is essential to check the effectiveness of demagnetization with a portable field strength meter. Whether or not a part needs to be demagnetized after MT inspection depends on a number of factors. The operation can be considered necessary for one of the following conditions: -The part is part of a moving assembly (adhering particles can cause wear); - The residual field can influence nearby equipment in the operation is based on magnetism; - The presence of a residual field can be detrimental to the cleaning of the part. Demagnetization is not necessary in the following cases: -The part is made of mild steel (low residual field); - The part will undergo a heat treatment; a second magnetic particle inspection is planned.

**1.4. Advantage of magnetic particle inspection**

- simplicity,
- speed (faster than penetrant testing),
- easy detection of through and underlying defects (about 2 mm); defects can be matted or obstructed,
- very good sensitivity of detection of "flat" defects (creating a large discontinuity of the field); example: cracks.

**1.5. Disadvantages of MT**

- average detection of non-linear defects,
- no trace of the control (except PV),
- risk of spurious background noise if the bead has too many surface irregularities,
- Impossible to detect deep defects (_ 2 mm deep),
- demagnetization mandatory after inspection,
- examination only applicable to ferromagnetic materials. Austenitic stainless steels are therefore outside the scope of this test.

## IV.3 Physical principles:

Magnetic testing, also known as the magnetic leakage flux method, is based on the particular behavior of ferromagnetic materials when subjected to the action of a magnetic field H. This magnetic field can be produced:

- by a rectilinear conductor through which a current of intensity I flows. At a distance r from the conductor the value of the field is given by the expression:

$$H = \frac{I}{2 \cdot \pi \cdot r}$$

$[A.m^{-1}]$

by a flat coil whose N circular turns of radius r are traversed by a current of intensity I. The magnetic field created at the center of such a coil has the value:

$$H = \frac{N \cdot I}{2 \cdot r}$$

**[A.m-1]**

by an elongated coil (solenoid) of length L with N circular turns through which a current of intensity I flows. The magnetic field created along the axis of such a coil has the expression :

$$H = \frac{N \cdot I}{2 \cdot r}$$

**[A.m-1]**

These different expressions having for dimension formula the quotient of an intensity expressed in amperes expressed in amperes over a length in meters, the unit of intensity of the magnetic field magnetic field will be the ampere per meter [A.m-1].

$$H = \frac{I}{L}$$

when a ferromagnetic material is placed in a magnetic field of a given uniform intensity H represented in the air by parallel and equidistant lines of force, a deformation of these lines is observed in the vicinity of this material and a concentration of these lines inside it

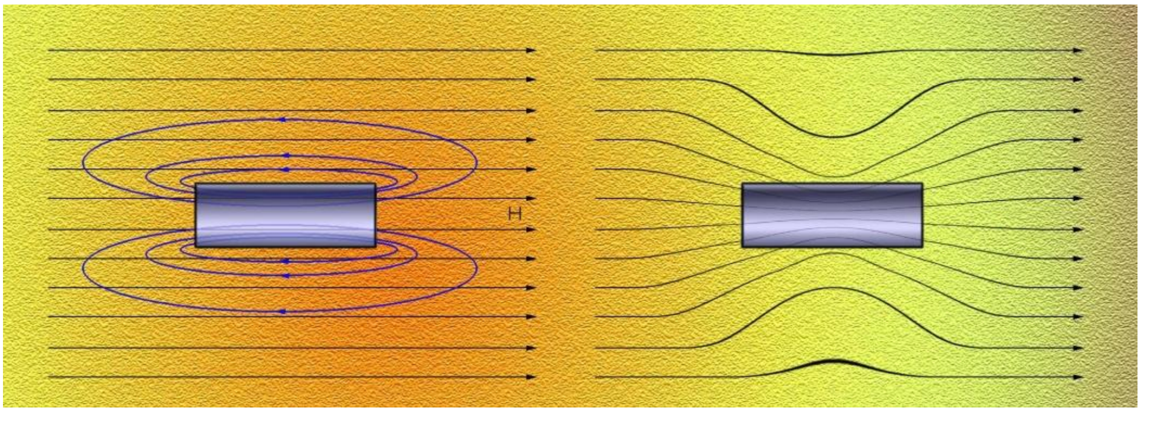



**Fig.IV.8 Concentration of lines of force in a ferromagnetic material**

This phenomenon is based on the directional effect of the external magnetic field on the circular atomic currents in the material. Under the influence of this field H, these currents, naturally disordered, become parallel and their own magnetic field is added to the exciting field H.

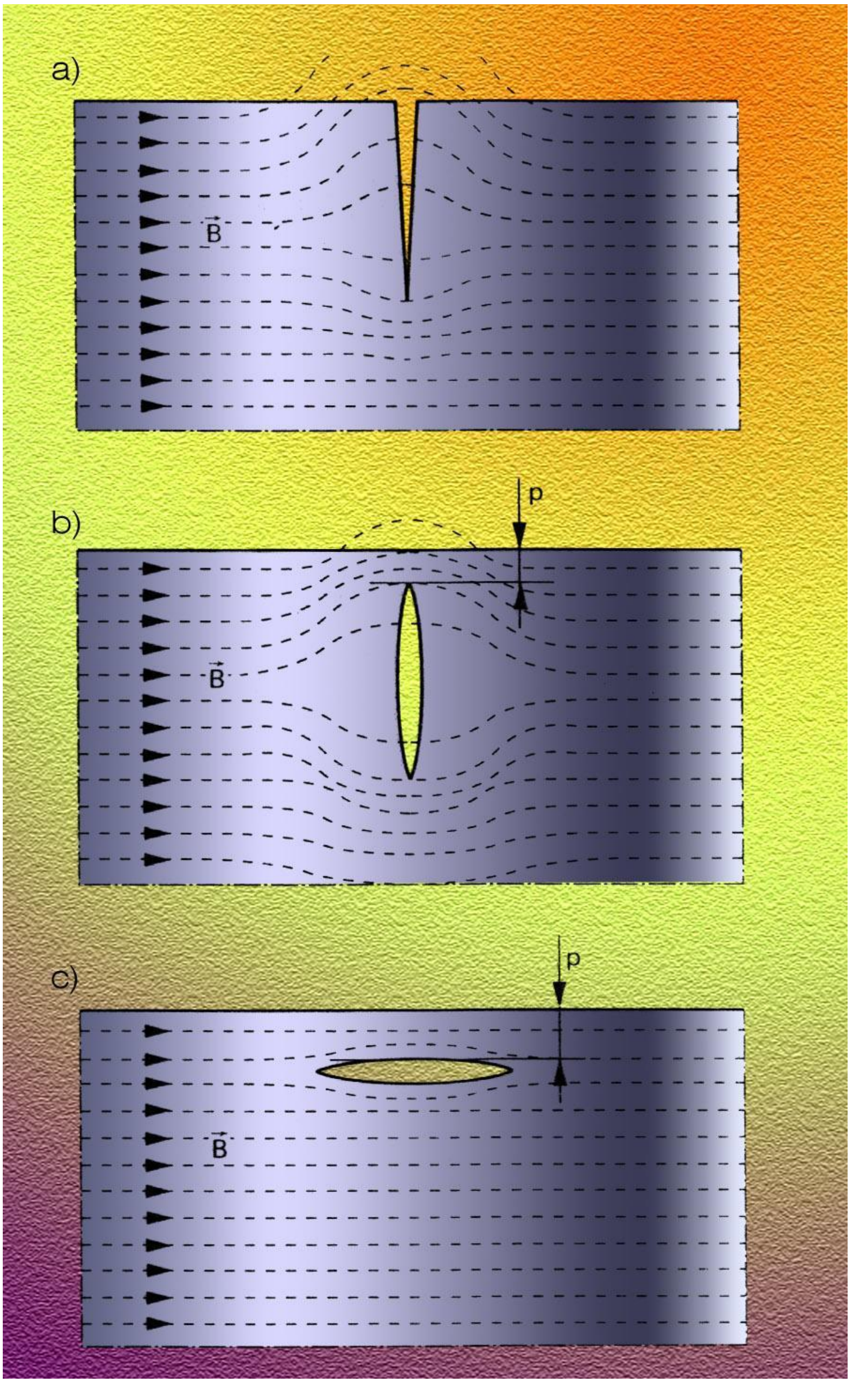



**Fig.IV.9** Influence of the depth and orientation of a defect on its detection

If the defect is open, the magnetic leakage flux in the air is maximal and its detection will be mostly assured ( figure a ). If the upper part of the defect is located at a distance ( or depth ) p from the surface of the part, there will be a concentration of induction lines in the metal ligament located above the defect and the magnetic leakage flux in the air will be very attenuated ( figure b ). In this case, the detection of the discontinuity will often be random and will depend, as we shall see, on the nature of the magnetizing field H.

Finally, if the defect is flat and parallel to the surface of the material, the induction lines in the latter will flow on both sides of the defect without any disturbance to their trajectory. In this case, no magnetic leakage flux will be observed at the surface of the defect (figure c).

## IV.4 Implementation

The examination of a part takes place in practically one time, corresponding simultaneously to the magnetization, the contribution of the developer and the visual reading.

The operation must be repeated if necessary, by changing the orientation of the magnetizing field, in order to be sure to detect all the defects whatever their orientation. The inspection operation must be preceded by a preparation of the part in order to put it in optimal conditions for examination: cleaning, degreasing, possibly demagnetization. The inspection itself will be followed by marking and locating operations, and possibly by demagnetization carried out under the conditions described below

**Fig.IV.10 Use of magnetic particle inspection in industry**

## IV.5 Application and limitations

Properly conducted, magnetic particle inspection has proven to be unmatched in its sensitivity for detecting the most minute surface defects on steel and other ferromagnetic alloys. The process, thanks to its numerous means of implementation and adjustment, is well adapted to the control of many types of manufactured parts. The search for subcutaneous defects by MT is possible but much more delicate, which means that ultrasonic testing is preferred, although it is possible to highlight heterogeneities not visible by any other process by MT; this is the case, for example, for the search for inclusionary clusters in thin sheets, but this test can unfortunately only be carried out on samples of small dimensions. One of the weaknesses of MT is indeed its relatively low productivity linked to the duration of handling and visual examination of the surfaces: partial or total automation is feasible but, in the end, it is the leakage flux measurement processes that have made it possible to envisage a high flow rate inspection of long steel products such as bars, tubes or wires. These processes are very efficient, since they allow the detection of cracks and lines with a depth of more than 0.3 mm on raw bars and of about 0.1 mm or sometimes less on drawn or calibrated products. This is why these leakage flux devices are included in the catalog of the main manufacturers of eddy current devices with which they share the market for the inspection of long products.

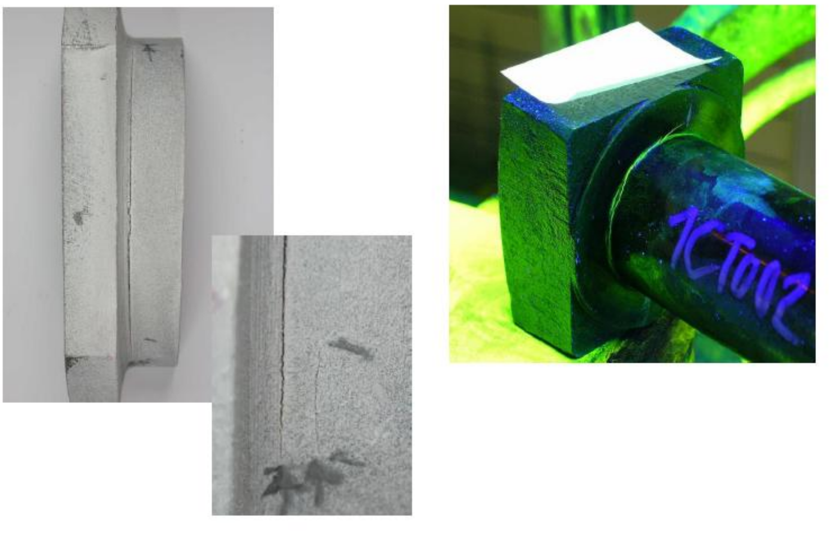


**Fig.IV.11 Results of the magnetic particle inspection**

# V. Ultrasons UT

# V. Ultrasons UT

## V.1 Introduction :

Ultrasonic control uses, like any sound system, mechanical vibrations at frequencies ranging from 0.1 MHz to 100 MHz. Ultrasound waves are used by some mammals such as whales or dolphins to communicate at distances sometimes very large or by others to navigate: this is the case of bats. The first industrial use of ultrasound dates back to the manufacture of maritime sonar (P. Langevin, 1918). It is directly derived from the discovery of "piezoelectricity" by P. and M. Curie (1880) which can generate a mechanical vibration and transmit it to a material. Since then, ultrasound has been used in medicine, electronics and material control.

Ultrasonic testing is based on the transmission, reflection and absorption of an ultrasonic wave propagating in the part to be tested. The emitted wave train reflects in the bottom of the part and on the defects and then returns to the transducer (which often plays the role of transmitter and receiver). The interpretation of the signals allows the positioning of the defect. This method has a high spatial resolution and the possibility to find defects in depth. The inversion step is simple, at least for geometrically and materially simple parts. On the other hand, it is a slow method because it requires an exhaustive mechanical scan of the part. It is often necessary to control several surfaces of the part to be able to make a three-dimensional representation of the defects.

Ultrasonic waves are mechanical vibrations whose frequency is higher than the audible range of a normal human ear (16 Hz to 16 KHz). They propagate inside materials with speeds that depend on the medium itself and the type of wave.

In metallic materials, the frequencies commonly used range from a few hundred kilohertz to a few dozen megahertz. In this frequency range, the damping in air is such that they hardly propagate.

## V.2 Principle

Ultrasonic testing is a relatively recent method of testing. The first industrial applications were carried out on an experimental basis on the eve of the Second World War, around 1935. Due to the slow evolution of testing equipment, which was dependent on the progress of electronics, the development of ultrasonic testing did not appear until about 1955. Since then, this testing method has become a powerful investigation tool. Today, it has a wide range of applications in metal, plastic and composite materials as well as in heterogeneous media such as concrete. This method of examination applies to: molded products, forged products, rolled products (sheets, rails), drawn products (tubes, rounds, etc.), welded, brazed or glued assemblies, etc. Ultrasonic inspection allows the detection of missing parts or discontinuities in the material of products in the rough or finished state, regardless of the method of manufacture.


**Fig.V.1** Ultrasound device

The USM 35: a fault-finding device

**two ultrasonic probes :**

1. The longitudinal wave probe (also the smallest) generates longitudinal waves and is used with the blue coupler. It is used to determine the propagation speed of longitudinal waves VL in materials.

2. The transverse wave probe (the largest) generates transverse waves with an angle of 0° and is used with the "honey" coupling. It allows to determine the propagation speed of the transverse waves VT in the materials.

However, the property of ultrasound is to propagate over distances of several decimeters, even several meters. Therefore, it is possible to detect small defects in parts whose thickness would not allow radiological control. In this sense, the ultrasonic inspection allows to measure the thickness of walls where one of the faces is inaccessible. In addition to the sound range, ultrasound corresponds to oscillatory frequencies above the limit of human audibility and extending in a wide range from 15 kHz to over 100 MHz. In industry, the vast majority of ultrasound applications use the 1 to 10 MHz range. These frequencies correspond to ultrasonic wavelengths of the order of a millimeter for common materials, a value that provides a good compromise between directivity, absorption, detectability of small defects, ease of realization of electronic equipment and reliable transducers. Ultrasound is a mechanical vibration that originates and propagates in any material support (solid, liquid or gas) with a certain elasticity. Thus, ultrasonic waves have properties related to the elastic characteristics of the material support. In liquids and gases (these are media with no shear strength), ultrasonic waves are essentially longitudinal vibrations, the material particles moving, with respect to their equilibrium position, parallel to the direction of propagation of the wave, generating compression-decompression fronts, themselves perpendicular to this direction. This type of wave is found in solids and moreover the most used in practice. However, another mode, using shear, may exist, which is called transverse wave mode for which the vibrations of particles are perpendicular to the direction of propagation. These two types of waves, the most commonly encountered in non-destructive testing (NDT), are volume waves; it is also possible to generate other types of waves whose existence depends in particular on the configuration of the propagation medium. First of all, there are surface waves, composite waves constituted by both longitudinal and transverse displacements, the best known and used are Rayleigh waves; other modes are possible and known: creeping Love waves, Bleustein - Gulyaev waves. When the support has dimensions of the same order of length as the wavelength, it generates particular vibratory modes: Lamb waves in sheets, these are dispersive waves with symmetrical or antisymmetrical mode of vibration; guided waves in rods and bars. Lamb waves are used industrially for the control of thin metal sheets and some composites.

Ultrasonic testing is a relatively recent method of examination, the first industrial applications of which were carried out, on an experimental basis, on the eve of the Second World War, i.e. around 1935. Due to the slow development of testing equipment, which was dependent on the progress of electronics, the development of ultrasonic testing did not begin until about 1955.

Since then, this testing method has been a powerful investigation tool. Today, it has a wide range of applications, including metallic, plastic and composite materials, as well as heterogeneous structures such as concrete. Thus, this method of examination applies to:

molded products, forged products, rolled products (sheets, rails), drawn products (tubes, rounds,...), welded, brazed or glued assemblies.

Ultrasound inspection allows the detection of missing parts or discontinuities in the material of products in the rough or finished state, regardless of the manufacturing process. However, the property that ultrasound has is to propagate over distances of several decimeters, even several meters. Therefore, it is possible to detect small defects in parts whose thickness would not allow radiological control. In this sense, the ultrasonic inspection allows to measure the thickness of walls where one of the faces is inaccessible. In addition to the sound range, ultrasound corresponds to oscillatory frequencies above the limit of human audibility and extending in a wide range from 15 kHz to over 100 MHz. In industry, the vast majority of ultrasound applications use the 1 to 10 MHz range. These frequencies correspond to ultrasonic wavelengths of the order of a millimeter for common materials, a value that provides a good compromise between directivity, absorption, detectability of small defects, ease of realization of electronic equipment and reliable transducers. Ultrasound is a mechanical vibration that originates and propagates in any material support (solid, liquid or gas) with a certain elasticity. Thus, ultrasonic waves have properties related to the elastic characteristics of the material support. In liquids and gases (these are media with no shear strength), ultrasonic waves are essentially longitudinal vibrations, the material particles moving, with respect to their equilibrium position, parallel to the direction of propagation of the wave, generating compression-decompression fronts, themselves perpendicular to this direction. This type of wave is found in solids and moreover the most used in practice. However, another mode, using shear, may exist, which is called transverse wave mode for which the vibrations of particles are perpendicular to the direction of propagation. These two types of waves, the most commonly encountered in non-destructive testing (NDT), are volume waves; it is also possible to generate other types of waves whose existence depends in particular on the configuration of the propagation medium. First of all, there are surface waves, composite waves constituted by both longitudinal and transverse displacements, the best known and used are Rayleigh waves; other modes are possible and known: creeping Love waves, Bleustein - Gulyaev waves. When the support has dimensions of the same order of length as the wavelength, it generates particular vibratory modes: Lamb waves in sheets, it is dispersive waves with symmetrical or antisymmetric mode of vibration; guided waves in rods and bars. Lamb waves are used industrially for the control of thin metal sheets and some composites.

The detection of internal defects by ultrasound is widely practiced in manufacturing control, in recipe control, in structural monitoring in service and in maintenance. Ultrasonic inspection is an original inspection method because of the remarkable sensitivity of ultrasonic echography to the slightest discontinuity or internal heterogeneity in materials, especially metallic ones. However, in ultrasonic echography, the choice of probing parameters and the interpretation of the signals collected are not always easy and require the intervention of specially qualified personnel.

Localization of defects in depth: it is easy when working with ultrasound. However, there is an area below the coupling surface where the defect echo can be embedded in the emission or interface echo, which can make both detection and localization uncertain. In-plane localization will be done in conjunction with manual probe position reading. Equipment to assist manual probing by copying the displacement of the probe now allows the use of presentations and promotes the analysis and presentation of results.

Dimensioning of the defects: it presents a legitimate concern of the controller in order to link them to criteria of technological harmfulness generally being the subject of a standardized or specific procedure. It is a delicate problem to which simple practical solutions can however be given. In theory, there are two cases, depending on whether the probe field is supposed to be larger or smaller than the average size of the defect. In the first case, the whole defect is illuminated by the beam and the amplitude of the return echo can be related to the defect size by means of diagrams. This method, called AVG method, is interesting but difficult to use, especially when the defect to be sized has an orientation and a morphology very different from the theoretical cases. When the defect is larger than the beam, which can sometimes be voluntarily obtained by using the narrow field of a focused probe, its apparent contour is traced, either by locating and quantifying the switch between background echo and defect echo, or by using the "-6 dB" rule which takes into account a ½ ratio between the maximum amplitude of the defect echo and the one obtained when the edges of the defect occlude about half the section of the ultrasound beam.

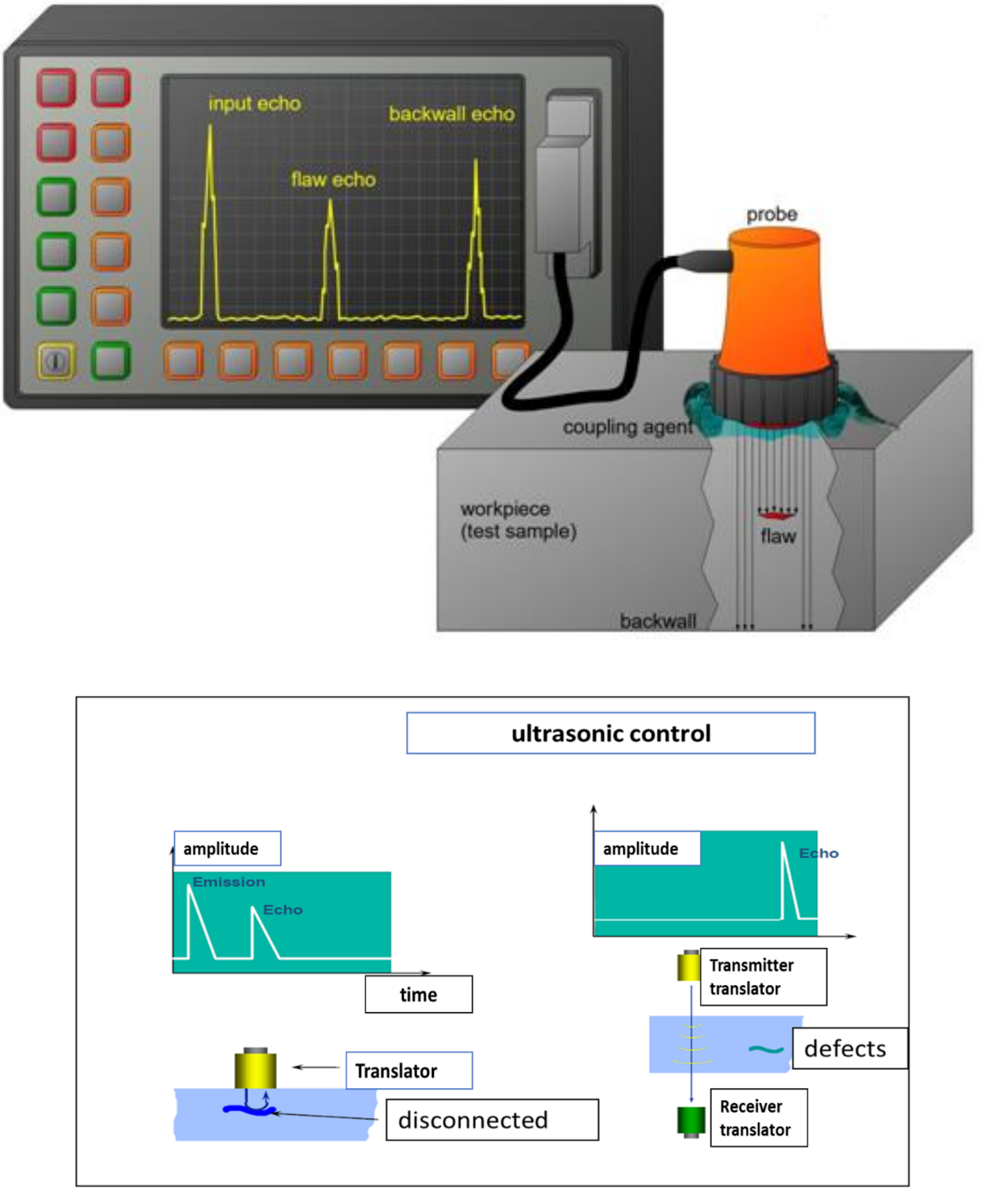



**Fig.V.2 Principle of the ultrasound method**

## V.3 Illustrations

The frequencies used for the control of metals are in the range of 1 to 10 MHz.

**MATERIALS:**

- Analog or digital U.S. stations;
- OL, OT and variable angle translators;
- Thickness gauges;
- Software for entering and monitoring thickness measurements.

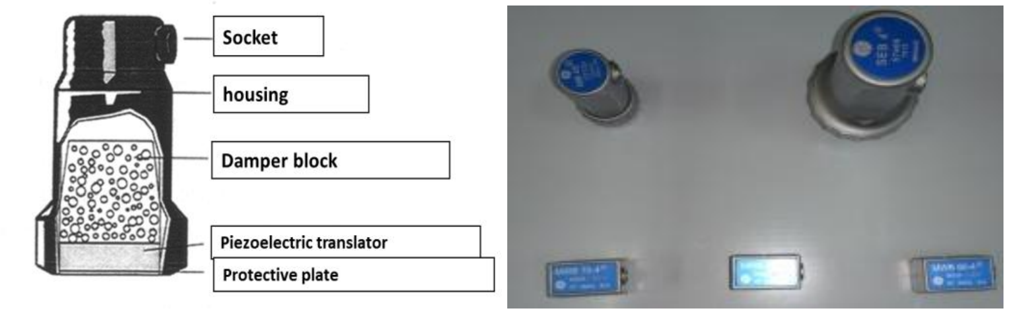



**Fig.V.3 Longitudinal translator**

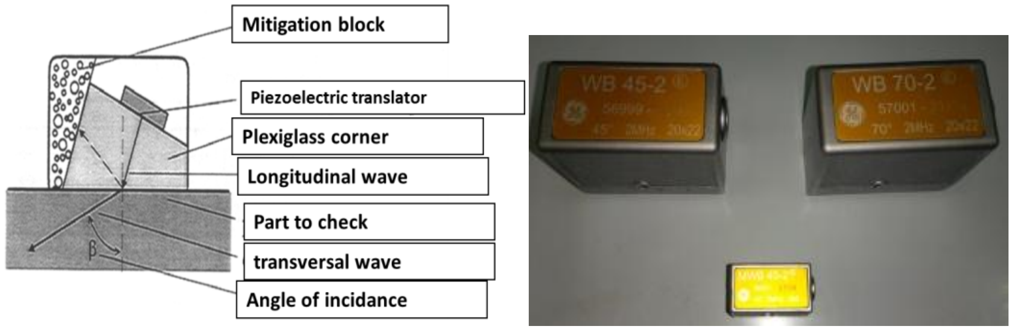



**Fig.V.4 Transversal translator**

| step | Step illustration | comment |
|---|---|---|
| 01 |  | Device configuration, choice of speed, measurement range, etc. |
| 02 |  | Calibration of the instrument with a standardized block. |

| | | |
|---|---|---|
| 03 |  | Final adjustment of the parameters to obtain a good ultrasound system |
| 04 |   | Calibration performed |
| 05 |  | practice of control |

**Fig.V.5 Ultrasonic inspection stage**

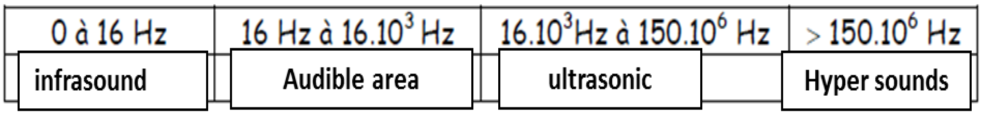
## V.4 Application

The detection of internal defects by ultrasound is widely practiced in manufacturing control, in recipe control, in structural monitoring in service and in maintenance. Ultrasonic inspection is an original inspection method because of the remarkable sensitivity of ultrasonic echography to the slightest discontinuity or internal heterogeneity in materials, especially metallic ones. However, in ultrasonic echography, the choice of probing parameters and the interpretation of the signals collected are not always easy and require the intervention of specially qualified personnel. Localization of defects in depth: it is easy when working with ultrasound. However, there is an area below the coupling surface where the defect echo may be embedded in the emission or interface echo, which can make both detection and localization uncertain. In-plane localization will be done in conjunction with manual probe position reading. Equipment to assist manual probing by copying the displacement of the probe now allows the use of presentations and promotes the analysis and presentation of results. Dimensioning of the defects: it presents a legitimate concern of the controller in order to link them to criteria of technological harmfulness generally being the subject of a standardized or specific procedure. It is a delicate problem to which simple practical solutions can however be given. In theory, there are two cases, depending on whether the probe field is supposed to be larger or smaller than the average size of the defect. In the first case, the whole defect is illuminated by the beam and the amplitude of the return echo can be related to the defect size by means of diagrams. This method, called AVG method, is interesting but difficult to use, especially when the defect to be sized has an orientation and a morphology very different from the theoretical cases. When the defect is larger than the beam, which can sometimes be voluntarily obtained by using the narrow field of a focused probe, its apparent contour is traced, either by locating and quantifying the switch between background echo and defect echo, or by using the "-6 dB" rule which takes into account a ½ ratio between the maximum amplitude of the defect echo and the one obtained when the edges of the defect occlude about half the section of the ultrasound beam.

## V.5 Types of ultrasonic waves:

The initial phenomenon of a sound or an ultrasound is always produced by an elastic body animated by mechanical vibrations due for example to a shock (tuning fork), to an electric impulse (thunder) or to an interrupted gas jet (siren).

Sounds in general are elastic waves. They differ from each other only in their frequency.




In non-destructive testing by ultrasound, the range used is between 105 Hz and 20.106 Hz.

We generally speak of a wave when it is a phenomenon that repeats itself after a certain time (T) called period.

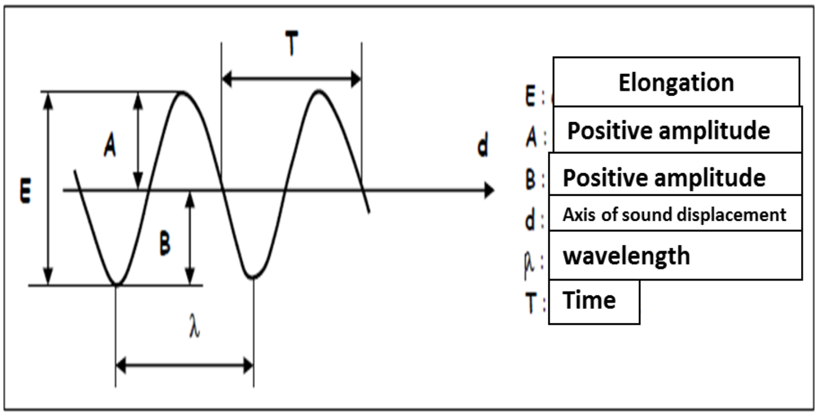



**Fig.V.6 Representation of sound vibrations (sinusoid).**

The frequency f (number of cycles per second) of reappearance of the phenomenon is therefore given by the inverse of the time:

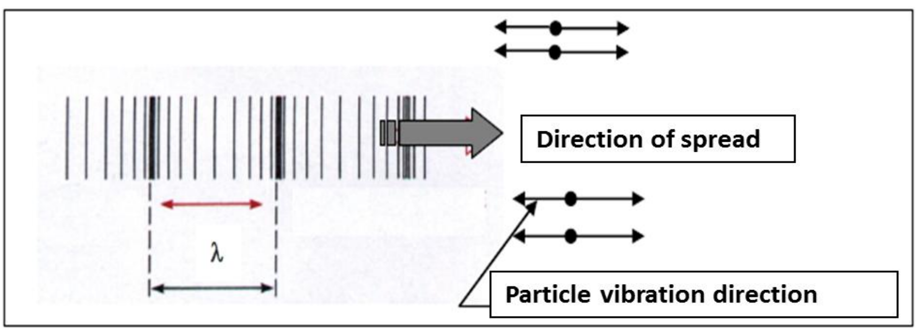
**f = 1/T** (**f** in **Hz** and **T** in **s**)

The space covered by the wave during a cycle or a period is called wavelength:

λ= **v T = v / f** (λ in **m, v** in **m/s** and **f** in **Hz**)

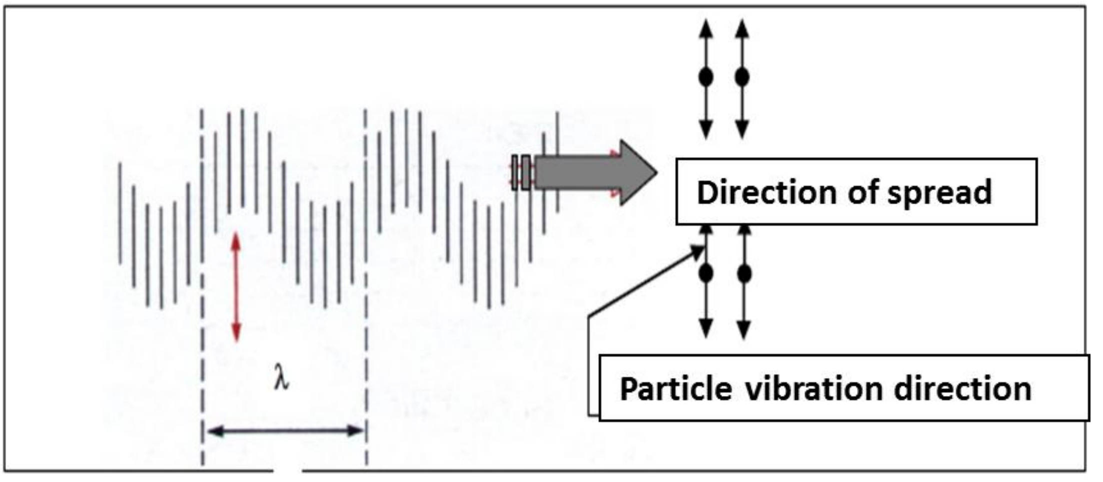
There are three types of waves:

- **a- Longitudinal or compressional wave**: the direction of vibration of the particles is parallel to the direction of propagation of the wave;

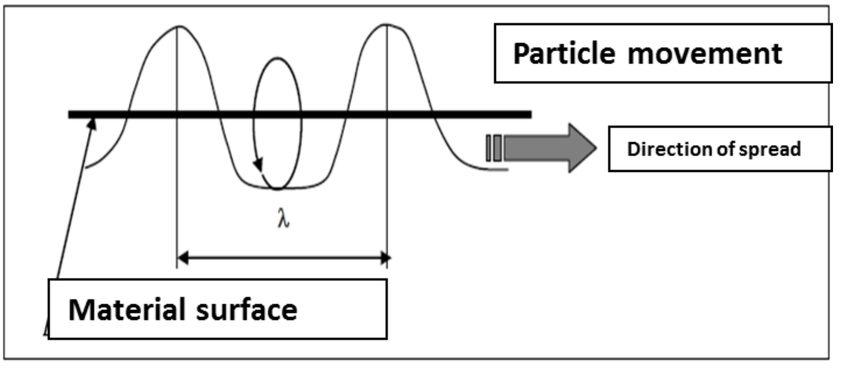


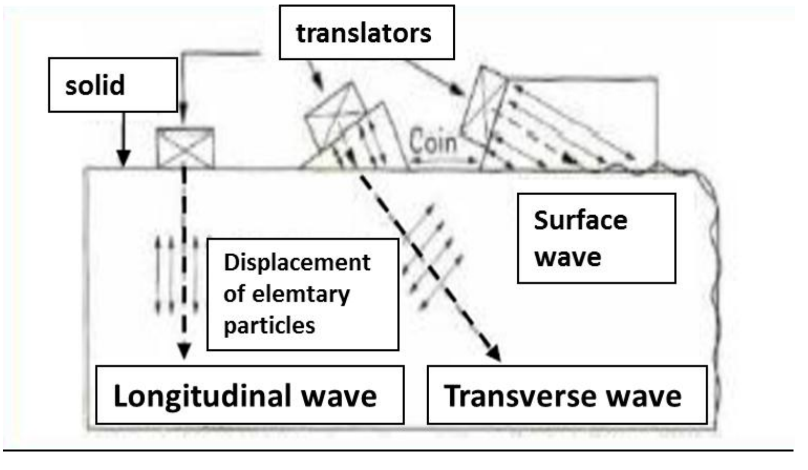

**b- Transverse or shear wave:** the direction of vibration of the particles is perpendicular to the direction of propagation of the wave.

These waves can only exist in solids because their existence is linked to a resistance to shear that neither liquids nor gases possess.




**b- Surface wave:** waves obtained by superposition of the two longitudinal and transverse waves parallel to the surface of the solid.




**FigV.7 Wave types and propagation modes of ultrasound in a solid**

Several types of ultrasonic waves are likely to propagate in solid media. These waves are differentiated from each other by:

- the shape and direction of the trajectories they impart to the particles of the material in which they propagate,
- the speed of propagation or celerity,
- the distance at which they are likely to propagate in the material.

There are four types of ultrasonic waves: longitudinal or compressional waves, transverse or shear waves, surface or RAYLEIGH waves and LAMB or plate waves.

**V.5.1 Longitudinal or compressional waves:**

These waves have the property to propagate in gaseous, liquid and solid media. Their propagation is accompanied, at each point of the material, by compression and dilation of the latter leading to variations in volume.

The propagation of a sound or ultrasound wave in a solid medium is not a simple phenomenon. Indeed, for a longitudinal wave, the displacements of particles in the direction of propagation also lead to displacements in other directions. speed of the wave is given by the expression: $V_L = \sqrt{\frac{E}{\rho}}$

Where E : longitudinal modulus of elasticity of the material as $E = \frac{\sigma}{\varepsilon}$ in Pascal (Pa)

s : normal stress (Pa),

e : relative linear expansion,

r : density of the material.

Whereas in the case of an infinite medium for which the POISSON coefficient m must be taken into account, the expression of the speed becomes:

$$V_L = \sqrt{\frac{E}{\rho}\frac{1-\mu}{(1+\mu)(1-2\mu)}}$$

It appears that the speed of propagation of the wave depends on the material considered since E, r and m are characteristic parameters of this material. The table below shows the speed or celerity of longitudinal waves for various common media.

Finally, longitudinal waves are widely used for non-destructive testing of materials and measurement of wall thickness.

**V.5.2 Transverse or shear waves:**

These waves propagate only in solid media. The propagation of this type of wave does not cause local changes in the volume of the material but simply a deformation of it by sliding (see figure)

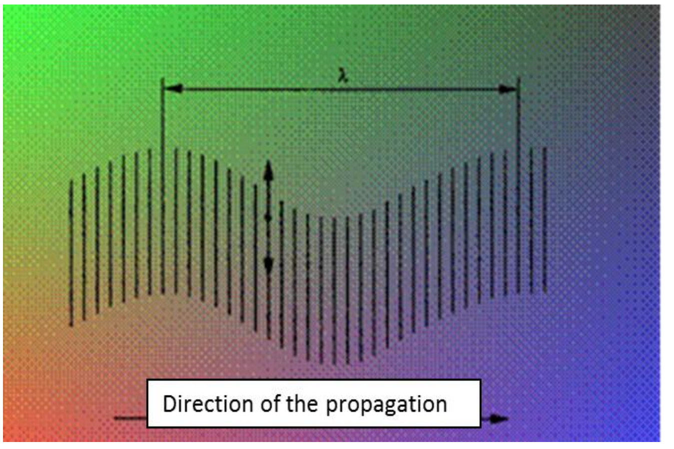



**Fig.V.8 Mode of propagation of transverse waves**

The particles are animated by an alternating rectilinear motion around an equilibrium position, the displacement of these particles being in planes perpendicular to the direction of propagation of the wave.

The transverse waves are no longer accompanied by a local change of volume of the material volume of the material but simply by a sliding of this one, the speed of this type of d'ondes is given by the expression: $V_T = \sqrt{\frac{G}{\rho}}$

Where G : the sliding modulus of elasticity of the material or Coulomb modulus expressed in pascal (Pa) such that: $G = \frac{\tau}{\gamma}$

t : tangential or shear stress,

g : unitary slip,

r : density,

Gaseous or liquid media are characterized by a modulus of elasticity of sliding G is zero, the transverse waves do not propagate in these media.

As for longitudinal waves, the table below shows the speed of transverse waves for different media.

Finally, transverse waves are widely used for the non-destructive testing of metallic media and especially welded assemblies.

**Tab.V.1 Waves and material**

| Environments | | Materials | Longitudinal waves (m.s-1) | Transverse waves (m.s-1) |
|---|---|---|---|---|
| Gaseous | | Air | 332 | |
| Liquids | | Water<br>Oil | 1480<br>1440 | |
| Solid | Material plastic | Plexiglass | 2680 | 1320 |
| | Metals | Aluminum<br>Magnesium<br>Titanium<br>Zirconium<br>Iron<br>Mild steel<br>Stainless steel<br>Copper | 6400<br>5740<br>5990<br>4650<br>5950<br>5900<br>5740<br>4760 | 3130<br>3080<br>3210<br>2300<br>3220<br>3200<br>3130<br>2325 |

### V.5.3 Surface or Rayleigh waves:

In some circumstances, transverse waves propagate at the free surface of a material and affect only a thin layer beneath it whose thickness is equal to or little different from a wavelength. The waves are then called surface waves or RAYLEIGH waves and propagate at a speed about 10% to that of transverse waves when moving in an unbounded medium.

The trajectory of the particles is the resultant of two displacement vectors: one, the most important, is perpendicular to the surface of the material, the other, of lower amplitude, is parallel to the direction of propagation and thus to the surface of the material.

The motion of the particles follows elliptical trajectories and the propagation speed of a surface wave is given by the expression :

$$V_S = 0.9\sqrt{\frac{G}{\rho}},$$

or $V_S = 0.9\,V_T$.

This type of wave is naturally encountered in the propagation of earthquakes.
In the practice of industrial controls, the RAYLEIGH waves are little used because of their great sensitivity to surface roughness.

**V.5.4 Lamb or plate waves:**

In sheets whose thickness is equal or slightly different from a wavelength, surface waves cannot be generated. In this case, other waves appear, these are the LAMB or plate waves which are of two main types: the first is comparable to a compression wave and the second type is characterized by a transverse mode wave.

2 Production of ultrasonic waves:

We saw that the frequencies of the ultrasonic waves which are used at the time of the industrial controls were included/understood between 250 KHz and 50 MHz, the most current field being included/understood between 1 and 10 MHz approximately.

The production of ultrasonic waves of very high frequencies uses transducers, a general term which designates a device capable of transforming a form of energy into another form of energy.

In this case, the transducers used will convert electrical energy into acoustic energy. They are of four types:

- Electromagnetic transducers,
- Electrostatic transducers,
- Magnetostrictive transducers,
- Piezo and ferroelectric transducers,

The obtaining of frequencies higher than 250 KHz can be satisfied only by means of piezo and ferroelectric transducers.

### V.5.5 Study of a longitudinal wave translator:

All the piezoelectric crystals and ceramics mentioned above are the seat of a deformation in the thickness under the action of an alternative potential difference. They thus play the role of a piston and generate compression or longitudinal waves.

The exploitation of the vibrations thus created for the non-destructive examination of a material requires the conditioning of the piezoelectric pellet in an assembly called translator or probe.

The role of this device is to allow the electrical excitation of the pellet, also called sensitive element, to protect it from mechanical shocks and finally to optimize the transmission and reception signals since the translator usually assumes these two functions.

The diagram on the right shows a single chip translator.

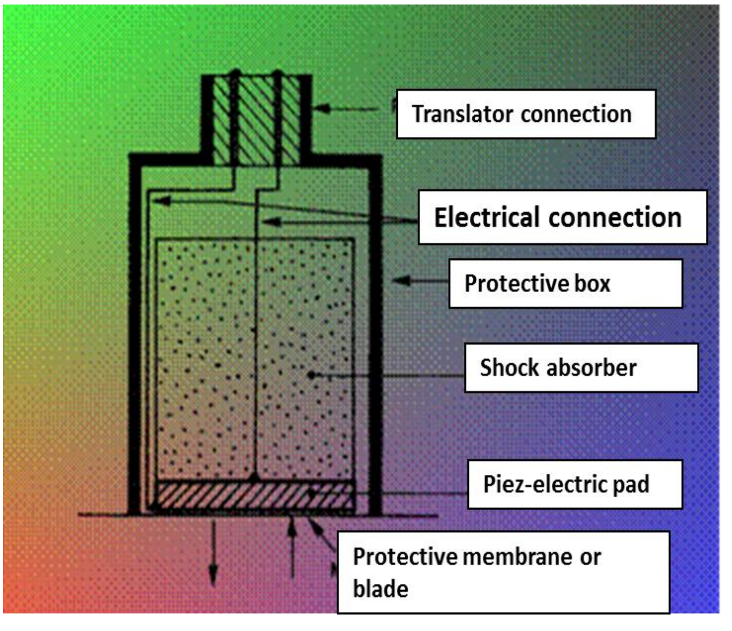



**Fig.V.9 a simple, single-plate translator**

This one is composed of :

- The piezoelectric chip,
- A damper whose role is to interrupt the vibrations of the piezoelectric pad as soon as the electrical excitation of this one has stopped.
- A flexible membrane or a hard blade for mechanical protection of the piezoelectric chip,
- Conductors ensuring the electrical connections of the chip,

- A protective case,
- A plug for connecting the translator to the power supply and reception system.

The figure below represents a bi-element piezo-electric translator. This type of translator is composed of two distinct piezoelectric pads, one of which acts as a transmitter of longitudinal waves and the other as a receiver of the wave possibly reflected by an obstacle.

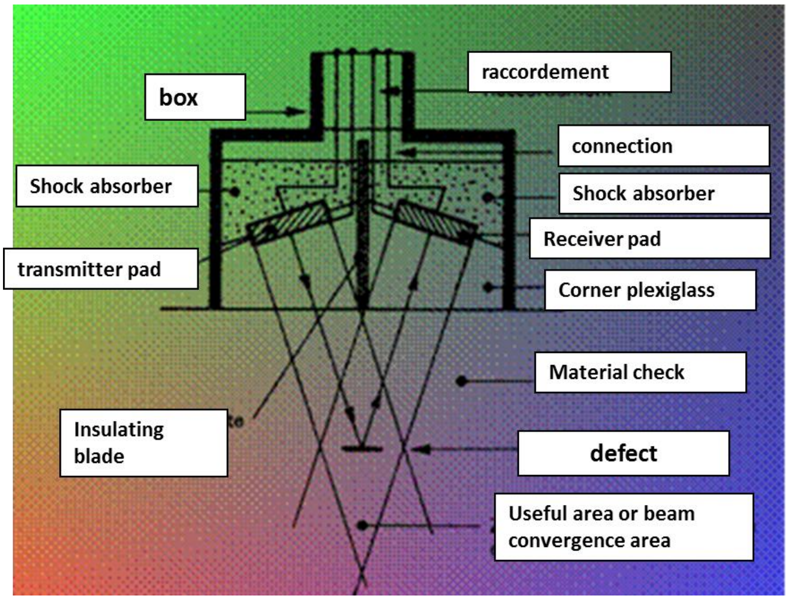



**Fig.V.10 a bi-element longitudinal wave translator**

The two pads and their damping are separated from each other by a plate which acts as an acoustic and electrical insulator in order to avoid operating interference. The other components are identical to those of a single-element translator.

Such transducers are used to search for defects located in the vicinity of the examination surface or when measurements must be made with a high degree of accuracy (thickness measurement).

### V.5.6 Study of a transverse, surface or LAMB wave translator:

The size of a quartz crystal makes it possible to obtain piezoelectric blades which, under the effect of an electric polarization, undergo a change of shape without change of volume by sliding of their faces.

It is therefore possible to transmit transverse or shear waves perpendicularly to the examination face in a material.

Unfortunately, this cannot be easily achieved because the liquid media providing the acoustic coupling between the translator and the tested part do not transmit this type of wave.
The realization of transverse wave translators exploits the phenomena at the interfaces.

**V.5.7 Characteristic of a piezoelectric chip:**

To obtain a maximum acoustic performance, it is necessary that the piezoelectric chip enters resonance for the excitation frequency f0 for which it was designed.

This condition is satisfied when the thickness e of this element is equal to the half wavelength corresponding to this frequency, i.e. :

$$e = \frac{\lambda}{2} \text{ , Or } \lambda = \frac{V}{f_0}$$

Where V : speed of propagation of the wave,

f0 : nominal frequency of the element.

Under these conditions: $e = \frac{V}{2 f_0}$

Let's take the example of a longitudinal wave translator with a nominal frequency of 4MHz, i.e. 4.106. In mild steel V = 5900 ms-1 = 5.9 10 6 ms-1. The thickness of the piezoelectric pad must be equal to :

$$e = \frac{V}{2 f_0} = \frac{5.9\times10^6}{2\times4.10^6} = 0.74\,mm$$

**PROPAGATION SPEED**

A good knowledge of the phenomena related to the propagation of ultrasound is therefore an essential basis for the practice of this type of control.
The fundamental principles of non-destructive testing by ultrasound lie in the analysis of the influence of defects, the type of structural heterogeneities, on the propagation of vibration waves in the material: reflection, refraction and transmission on the interfaces, attenuation in the matrix related to the phenomena of absorption and scattering, variable propagation speeds depending on the direction.
The speed of the wave depends on the nature of the material that carries it and the type of wave:

**Longitudinal wave**

$$V_L = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}}$$

- E : Young's modulus of material
- ρ : Specific mass of material
- ν : Poisson's coefficient

**Onde transversale :**

$$V_T = \sqrt{\frac{E}{2\,\rho\,(1+\nu)}}$$

**Surface wave**

$$V_S = 0{,}9\ V_T$$

**EXERCICE :**

a) Calculate the propagation speed of ultrasonic waves in steel, in longitudinal wave, transverse wave and surface wave.

We give: E = 21 1010 N /m² ; ρ = 7,8 103 Kg/m3 et v = 0,28.

b) Calculer la vitesse de propagation des ondes ultrasonores dans l'aluminium, en onde longitudinale, en onde transversale et en onde de surface.

We give: E = 7 1010 N /m² ; ρ= 2,51 103 Kg/m3 et v= 0,34.

**Tab.V.2 Examples of ultrasound speeds (longitudinal waves) in matter**

| | Acoustic speed and impedance | | | |
|---|---|---|---|---|
| Material | density | Longitudinal wave velocity | transverse wave velocity | Acoustic impedance |
| Aciers | 7.8 | 5 900 | 3 250 | 46 |
| Fontes | 7.2 | 4 600 | 2 150 | 33 |
| Aluminium | 2.7 | 6 300 | 3 100 | 17 |
| Cuivre | 8.9 | 4 700 | 2 250 | 42 |
| Laiton | 8.5 | 4 500 | 2 100 | 38 |
| Béton | 2.5 | 4 500 | | 11 |
| Muscle | 1.0 | 1 600 | | 1.6 |
| Araldite | 1.2 | 2 500 | 1 050 | 3 |
| Plexiglas | 1.2 | 2 700 | 1 100 | 3.2 |
| Verre | 2.6 | 5 650 | 3 400 | 14 |
| Huile | 0.8 | 1 500 | | 1.2 |
| Glycérine | 1.3 | 1 900 | | 2.5 |
| Eau | 1.0 | 1 480 | | 1.5 |
| Mercure | 13.6 | 1 450 | | 20 |
| Quartz | 2.7 | 5 750 | | 15 |
| Titane de baryum | 5.7 | 4 400 | | 35 |
| Air | $1.3\ 10^{-3}$ | 330 | | $4\ 10^{-4}$ |

**Advantages**

- The method lends itself well to the detection of localized defects in the volume of the part and it presents a great sensitivity, in particular for the search for plane defects.
- Control on metals, plastics, various materials.
- Controllable thicknesses are too important.
- It can be used either on site or in the workshop and lends itself well to automation.

**Inconveniences**

- The sensitivity of the method is strongly influenced by the orientation of the defect surface with respect to the main direction of the acoustic beam.
- It is necessary to interpose an intermediate "coupling" medium between the translator and the part to ensure the continuity of the propagation.
- The interpretation of the nature of the defects and their dimensions requires qualified personnel with extensive experience.
- The implementation is difficult on some materials.

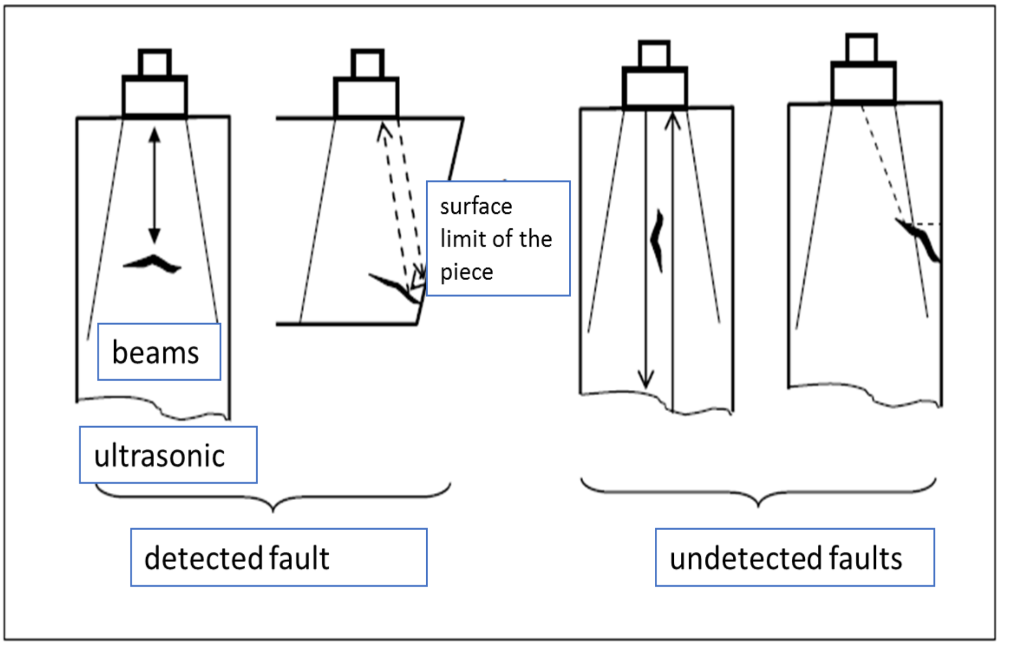



**Fig.V.11 Disadvantage of the ultrasound method**

## V.6 Evaluation of the Young's modulus Materials

### V.6.1 Thickness measurement

To perform the calibration using a longitudinal wave probe with the help of the standard block:

- First, we measure the thickness of the standard block with a caliper (e = 100 mm)

- We put the probe on the steel block after mastering the gel and adjusting the speed of the waves corresponding to the steel which gives the thickness 100mm displayed on screen.
After calibration we take any piece with unknown thickness, using the U.S. device we obtain its thickness.

### V.6.2 Speed measurement:

**Method 1:**
After calibration, we determine the velocities of the O.L. in the following materials:

Aluminium, Bronze, Plexiglas.

**-Aluminium:** we put the probe on a cylindrical piece of Al of height h=29mm then we vary the speed of the waves until we obtain h=29mm displayed on screen. So, the speed of U.S. waves in Al is V=6271 m/s.

**-Bronze:** the same thing as the Al h=29 mm we vary the speed until we obtain the height 29 mm displayed on screen. So, the speed corresponding to the Bronze is V=4656 m/s.

**- Plexiglas:** same as for the two previous materials, only for Plexiglas h=23mm by varying the speed we get h=23 mm displayed on screen so the speed of U.S. waves in Plexiglas is V=2802 m/s.

**Comparison of results:**

| Material | Table values (m/s) | Experimental values (m/s) |
|---|---|---|
| Steel | 5900 | 5920 |
| Aluminium | 6300 | 6271 |
| Bronze | / | 4656 |
| Plexiglas | 2700 | 2802 |

**Conclusion:** the values in the table and the experimental ones are almost identical; the difference is more or less 100 m/s (a difference that is not important).

**Method 2:** In this method the velocities are deduced by calculation using the following expression: $\mathbf{Ci} = \frac{Hi.Co.Xo}{Ho.Xi}$

Donne: Ho=100 mm, Co=5920 m/s, Xo= 100 mm.

**Aluminum:** Hi= 29 mm, xi= 29mm

$CAl=\frac{29x5920x100}{100x27}$ = 6359m/s

**Bronze:** Hi=29 mm, Xi= 38 mm

$CBr=\frac{29x5920x100}{100x38}$ = 4518 m/s

**Plexiglas:** Hi=23 mm, Xi= 50 mm

$Cpl=\frac{23x5920x100}{100x50}$ = 2723 m/s

**Comparison of results:**

| Material | Table values (m/s) | Experimental values (m/s) |
|---|---|---|
| Steel | 5900 | 5920 |
| Aluminium | 6300 | 6359 |
| Bronze | / | 4518 |
| Plexiglas | 2700 | 2723 |

### V.6.3 Damping of U.T. in materials:

Using the sample as a stair step, we measure the thickness of the last step 7 mm keeping a measurement range of 100 mm and then, on the screen it is displayed different visible echoes which are:

-the first is the U.S. path

-the second is the return of the U.S. waves

-the rest is the back and forth (edge effect)

**V.6.4- Search for defects in O.L:**

**a) Depth of a cylindrical hole:**
To carry out this test we use the standard block, we measure the depth of the hole with a ruler and we find h= 45 mm; using the U.S. device (at O.L.) we find the same thing h= 45 mm, so we can detect any defect with the U.S. device.
**b) Fault finding:** For an angle welded part analyzed by O.L we find a defect of 18 mm depth and 70 mm from the end.

**2- Search for defects in O.T.:**

**a) Calibration of an oblique probe:** The probe used is that of 4MHz and the shoe of 70°. The calibration is carried out with the help of the standard calliper and R=100 mm is found.

**b) Search for a hole on the calibration block:** By moving the probe on the standard block we detect a small hole of depth 15 mm, using the ruler we find that it is exactly 15 mm deep.

**c) Control of welds:** For a welded part of thickness e=25 mm we search for defects by U.S., using an O.L. probe we find the following defects:

| Detection | Depth (mm) | Distance to probe application point (mm) |
|---|---|---|
| 1 | 18 | 50 |
| 2 | 12 | 56 |
| 3 | 22 | 61 |
| 4 | 19 | 54 |
| 5 | 19 | 54 |

The part to be controlled is full of surface defects which are due to the lack of penetration. The different difficulties encountered are the different echoes of the edge effect and the tiny defects which require a great precision to detect them.

### V.6.5 Evaluation of the Young's modulus:

From the relations below, we express the Young's modulus as a function of Cl, Ct and μ.

$\mu = 7850\ kg/m^{3,}$   $\sigma = 0.3$

**Longitudinal speed** : $Cl = \sqrt{\frac{E(1-\sigma)}{\mu(1+\sigma).(1-2\sigma)}}$

$$E = \frac{Cl^2 \mu(1+\sigma).(1-2\sigma)}{1-\sigma} = \frac{(5920)^2.7850.(1+0.3).(1-0.6)}{1-0.3}$$

E = 204370 MPa.

**Transverse speed:** $Ct = \sqrt{\frac{E}{2\mu.(1+\sigma)}}$

$E = Ct^2.2.\mu.\ (1+\sigma) = (3240)^2.2.7850.\ (1+0.3)$

E = 214256 MPa.

**V.6.6 Conclusion:** the value of Young's modulus found is around 210000 MPa (of steel) which shows the precision of ultra sound control.

# VI. Eddy current ET

# VI. Eddy current

## VI.1 Introduction

When a conducting body is placed in a magnetic field that varies in time or space, induced currents develop inside the material in a closed circuit. A coil carrying an alternating current generates induced currents which in turn create a magnetic flux. This magnetic flux, by opposing the generating flux, modifies the impedance of the coil. The presence of a fault disturbs the circulation and distribution of eddy currents. The variation of the impedance detectable at the level of the excitation coil is used to detect surface defects. In general, a comparative method is used which consists in measuring the difference between the impedance Z of the coil on the part to be studied and the impedance Z0 of a reference part without defect. This procedure therefore requires prior calibration. This is how eddy currents are commonly used to search for fatigue cracks during aeronautical maintenance of holes at rivet locations..

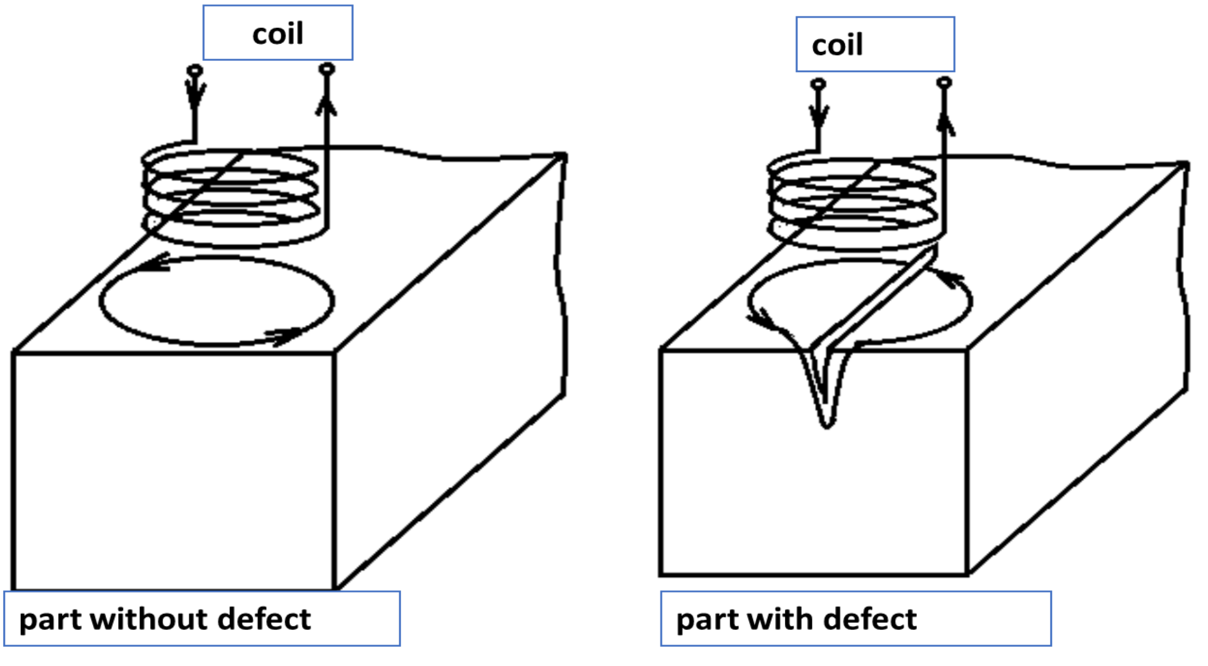



**Fig.VI.1 Principle Modification of the eddy current path**

The control of heat exchanger tube bundles has always been the preferred field of use of eddy currents. In recent years, the inspection equipment has evolved to the point of becoming very compact. This allows a great mobility to the people intervening in multiple configurations.

Eddy current allows the non-destructive examination of electrically conductive materials. Their use does not require a coupling agent and can be conducted through a light deposit. This method provides an excellent ratio of sensitivity to inspection speed.

By the multi-frequency eddy current method, ENACT/SPA offers the possibility to test non-magnetic steel tubes.

The inspection of heat exchanger tubes using the multi-frequency eddy current method with an internal probe consists of studying the impedance variations of the coils of a probe placed near a non-magnetic conductive part. The use of several frequencies allows the combination of signals to eliminate those created by the passage of the probe at the location of intermediate plates, and to visualize and quantify the underlying degradation.

It is conceived in the presence of a defect constituting an electrical discontinuity which disturbs the circulation of the eddy currents and generates a variation of impedance detectable at the level of the excitation coil (or any other winding located in the field). This simple principle is mainly used to detect surface defects because the eddy currents tend to gather on the surface of the conductive bodies (skin effect).

The observation is made by visualizing on an oscilloscope the variations of the electrical impedance of the probe between a healthy zone and a defective zone.

This method is applicable on all electrically conductive materials and only allows to highlight superficial defects.

The advantages of the Multifrequency Eddy Current method are:

- Reporting system with mapping,
- Semi-automatic analysis system,
- Rigid and flexible axial probes,
- Rotating probes,
- Digital data storage (traceability),
- Reference tubes with metrology report.

The applications that can be presented by ENACT/SPA are:

- Periodic control of the integrity of the tubes of exchangers, condensers, air conditioners
- Search for defects such as: lack of material of internal or external origin, vibratory wear, corrosion by isolated or generalized pitting, cracking, ammonia,
abrasion, erosion.
- Follow-up and evolution of thickness losses in time (evolution kinetics)

It is conceived in the presence of a defect constituting an electrical discontinuity which disturbs the circulation of the eddy currents and generates a variation of impedance detectable at the level of the excitation coil (or of any other winding located in the field). This simple principle is mainly used to detect surface defects because the eddy currents tend to gather on the surface of the conductors (skin effect).

The observation is made by visualizing on an oscilloscope the variations of the electrical impedance of the probe between a healthy zone and a defective zone.

This method is applicable on all electrically conductive materials and only allows to highlight superficial defects.

## VI.2 DEFINITION AND PRINCIPLE OF EDDY CURRENT CONTROL

When a conductive body is placed in a magnetic field that varies in time or space, induced currents develop in a closed circuit inside it: these are the Foucault currents (French physicist 1819 - 1868).

Thus a coil traversed by a variable current, alternating for example, generates such induced currents which, creating themselves a magnetic flux which opposes the generating flux modifying the impedance of this coil.

It is the analysis of this impedance variation which will provide the indications usable for a control. Indeed, the path, the distribution and the intensity of the eddy currents depend on the physical and geometrical characteristics of the body considered as well as on the excitation conditions (electrical and geometrical parameters of the coil).

## V*I*.3 MATERIAL AND IMPLEMENTATION

- Digital multi-frequency eddy current generator with multiplexed or non-multiplexed frequencies, adjustable from 1000 Hz to 4 MHz;
- Multi-channel thermal graphic recorder for CF signal visualization;
- Storage of CF signals on digital magneto-optical disk;
- Probe puller-pusher device with adjustable speed;
- Various sensors such as axial probe, rotating probe, encircling coil, with or without saturation device, each specificity being adapted according to the geometry and the nature of the controlled material.

**Fig VI.2 Eddy current fault-finding apparatus**

**Fig.VI.3 Eddy current probes**

## VI.4 APPLICATIONS

### Control of tubes, bars and wires

The eddy current flaw detection technique using encircling coils is very well adapted to the high speed industrial inspection of all long metal products. It is widely used in the metallurgical industry to detect surface defects of various types on wires, bars and tubes of small diameters.

Such a technique can reveal, on these products, not only superficial health defects such as cracks, pits and small straws, but also geometrical defects such as sudden variations in diameter or wall thickness, structural heterogeneities such as coarse-grained areas, etc.

However, the encircling probe method is not sensitive enough when long products with a large diameter are to be inspected or when very small defects are to be found in well-graded products with a good surface finish, such as drawn products. In this case, it is preferable to use the so-called rotating probe process, based on the inspection of the surface along helical tracks: 2 or 4 pick-up probes rotate at high speed around the product itself, which is slowly moving inside the rotor of the machine. The probes are made of small coils that touch the surface of the product and are therefore very sensitive to fine longitudinal defects such as long cracks called lines, whose depth can be less than 100 mm.

The inspection of tubes in service is an important application of eddy current testing, given the importance of the maintenance of boilers, exchangers and especially steam generators in nuclear power plants. The tubes are probed from the inside using a "ferret" which is pushed and pulled by a cable and consists of one or more longitudinal coils concentric to the tube.

**Control of flat surfaces**

The control of flat surfaces, as far as the search for small cracks, fissures or local heterogeneities is concerned, can be carried out with the help of a pick-up probe that is slid with or without contact. Very fine defects can be detected on any conductive product, however, the punctuality of the sensitive zone directs the use of the process more towards the control of small surfaces corresponding to the critical zones in the degradation of a mechanical part rather than towards the examination of large surfaces such as sheets.

This is why eddy currents are commonly used to search for fatigue cracks during maintenance operations on aeronautical equipment. The inspection can be manual or automatic using a manipulator arm to move the probe and an information processing system leading to a mapping and archiving of the inspection results.

**Fig.VI.4 Aeronautical applications Erosion or Corrosion of a blade**

There are also some applications of eddy currents in the field of dimensional measurements, the interest being to have a method of measurement without contact with the part, which is not the case in traditional metrology or with ultrasonic processes. This way, tube diameters can be measured and wall thinning can be highlighted.

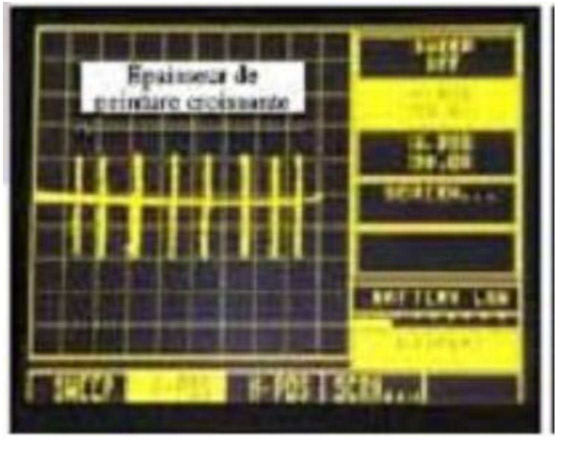


**Fig.VI.5 different thicknesses of paint on an aluminum panel (aircraft fuselage)**

Finally, it should be noted that eddy current detection processes are used outside of industry in a wide variety of fields, the best known of which is the detection of metallic objects in an insulating environment. Whether it is for mine detectors or security devices in airports or other public places, detection is based on the use of large coils capable of creating a field large enough to be disturbed at a good distance by the presence of a metal object in which eddy currents will develop.

## VI.5 PERFORMANCE AND LIMITATIONS

The possibilities offered by the sensitivity of detection and the easy automation of the eddy current inspection are highly appreciated in the industry. The absence of contact between the probe and the part to be inspected, the possibility of high-speed movement and the ease of integration of the process into production lines give this inspection technique a definite advantage over other processes.

Eddy currents are also an exceptionally accurate means of control, despite the complexity of the electromagnetic phenomena involved and the multitude of action parameters. This excellent reproducibility is very important for maintenance checks and for the quality of equipment calibration procedures.

It is possible, with eddy currents, to detect minute surface heterogeneities, however this high sensitivity concerns of course all disturbing parameters.

**Advantages**

- High detection sensitivity;
- Fast control;
- Probe adaptable to the product to be controlled;
- Recording of results (follow-up over time)

**Disadvantages**

- Method limited to the control of conductive materials;
- Low penetration in the material (a few mm);
- Sensitive to disturbing phenomena (work hardening, surface deposits): need for a standard specific to each control.

**Fig.VI.6 Eddy Current Testing**

# VII. Infrared thermography TT

# VII. Infrared thermography

## VII.1 Introduction:

Infrared thermography can be used to locate corrosion areas in high temperature enclosures. By applying the principle of heat exchange between the walls of an equipment and the external environment, the corroded areas eventually present a higher temperature than the non-corroded areas. This method allows to quickly locate the areas of lack of thickness which can be developed by more precise measurements by ultrasound.

The thermographic inspection consists in determining the hot spots with an infrared camera.


**Fig.VII.1 Infrared camera**

**Infrared thermography** is a technique allowing to observe thermal scenes from a distance and without contact, and to measure temperatures with a variable precision according to the criteria sought.

From absolute zero (-273°C), all bodies radiate energy. This emitted energy is dependent on two main factors which are:

- The temperature of the body;
- The type of material and its surface condition.

In summary, the hotter a body is, the more radiation it emits. The measurement of this energy is possible thanks to a measurement system called "infrared camera", or more technically "infrared radiometer". The military and medical sectors have contributed to the development of this technology.

**DEFINITION**

Infrared thermography "TIR" is the science of acquiring and analyzing thermal information using remote thermal imaging devices.

The French standard A 09-400 defines infrared thermography as "Technique for obtaining the thermal image of a thermal scene in the infrared spectral range by means of an appropriate device".

Infrared thermography is used in the field of conditional operation monitoring to optimize maintenance tasks without interrupting the production flow and to reduce maintenance costs to a minimum.

## VII.2- PRINCIPLE

The infrared camera captures the radiation emitted by a thermal scene through a transmitting medium. The radiometric system converts the radiation power into digital or analog signals: these are transcribed into temperature by the computer and transformed into light points on a screen. The image thus obtained is called "thermogram".

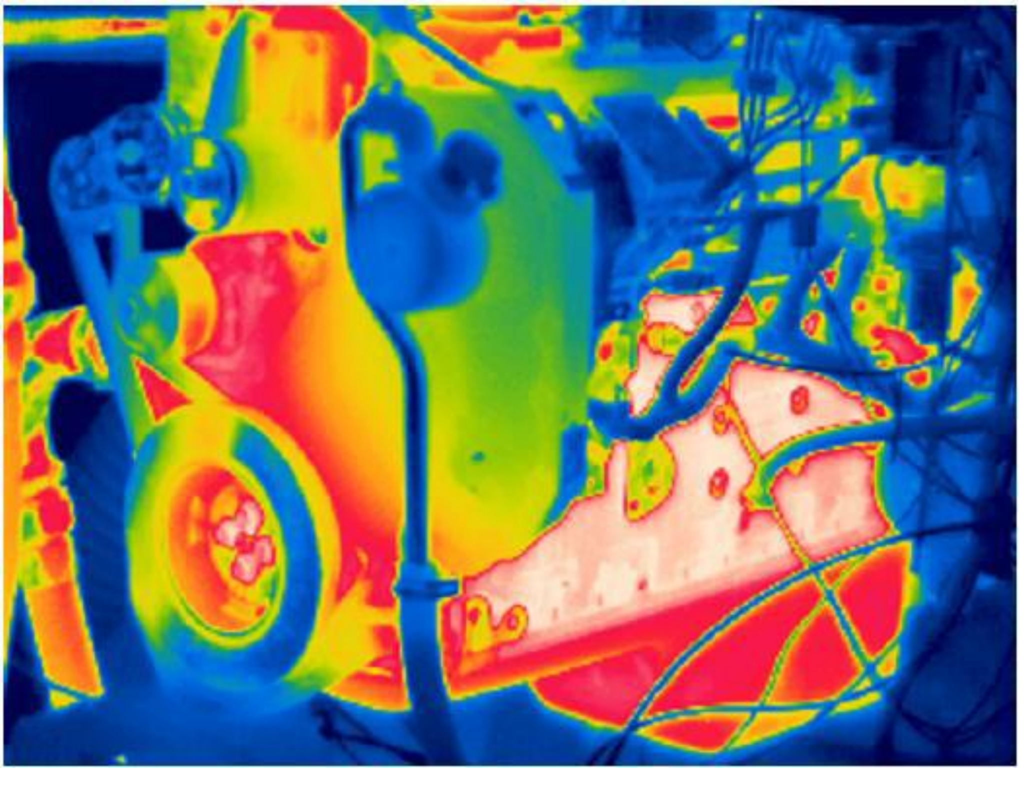


**Fig.VII.2 Image example thermogram of an engine**

## VII.3 LAWS OF INFRARED RADIATION

**The electromagnetic spectrum**

Visible light, radio and TV waves, and X-rays are electromagnetic radiation. The visible range extends from wavelengths ranging from 0.4 to 0.8 µm. The infrared band extends from 0.8 to 1000 µm. In infrared thermography we generally work in a spectral band that extends from 2 to 15 µm and more specifically in the windows 2-5 µm and 7-15 µm.

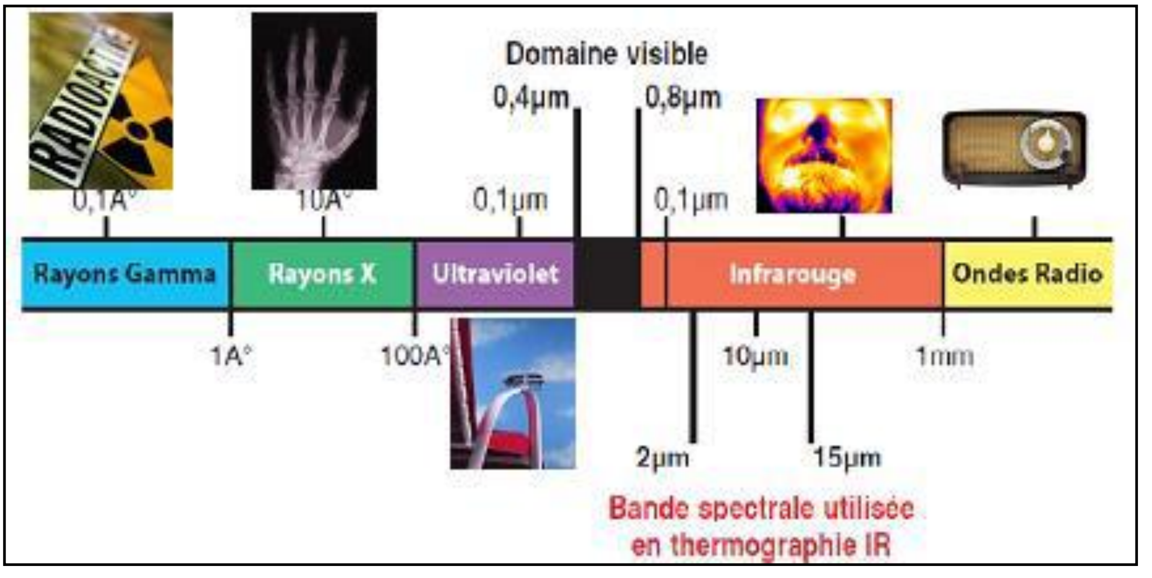



**Fig.VII.3 Electromagnetic radiation**

# VIII. OIL ANALYSIS OT

# VIII. OIL ANALYSIS

## VIII.1 INTRODUCTION

Lubrication is of paramount importance in the operation of all mechanical systems. Along with infrared thermography and vibration analysis, oil analysis is one of the most interesting methods for ensuring the health and longevity of machinery. It is easy to implement and the information provided allows for accurate diagnoses. Moreover, the investment is low in return for the information provided and the costs generated by unscheduled shutdowns.


**Fig.VIII.1 Oil analysis equipment**

## VIII.2 USEFULNESS OF OIL ANALYSIS

Lubricant is to the machine as blood is to the body. It reflects the behavior and condition of the system in which it circulates. Monitoring the physical and chemical characteristics of the lubricant allows us to assess the state of degradation of the oil and, consequently, its ability to fully perform its initial lubrication functions. The evolution of this degradation can be an indicator of the operating conditions of the equipment. It will allow to optimize the frequency of oil changes, in the case of important loads. The monitoring of the contamination allows, in the case of pollution by particles internal to the machine, to locate the defective component, to appreciate the evolution and the type of wear and in the case of pollution by external agents, to appreciate their nature and their origin. In order to be able to make the most accurate diagnosis possible of an oil charge and the equipment it lubricates, it is advisable to regularly monitor the evolution of the oil's characteristics and to compare the results obtained from each analysis from one time to the next, and this in relation to the characteristics of the new oil. If there is a sudden change in the characteristics or if the values are too far from the initial values, action should be taken, either on the equipment or by changing the oil charge. An analysis result taken in isolation is not very relevant for the conditional maintenance objectives.

## VIII.3 FIELDS OF APPLICATION OF OIL ANALYSIS

**Thermal engines**

- Air filtration sealing problems;
- Coolant seepage;
- Injection system maladjustment;
- Mechanical condition of the engine: wear;
- More or less severe driving or operating constraints.

**Gearboxes**

- Bad condition of a bearing or a bearing;
- Defective transmission: damaged gears;
- Additive performance;
- Assessment of the residual characteristics of the lubricant;
- External pollution: water, dust...

**Compressors**

- Mechanical condition;
- External pollution: water, silica... ;
- Lubricant evolution in service : deposits, oxidation...

**Hydraulic systems**

Pollution of the circuit : solids, water... ;

Wear and tear of components: pumps, motors, distributors... ;

Filtration efficiency: pollution level... ;

Residual characteristics of the lubricant.

## VIII.4 SAMPLING FREQUENCY - PARAMETERS TO BE MEASURED

The sampling frequency must be set according to the criticality of the equipment monitored.

This frequency will be further modulated according to the following elements:

The permanent load applied to the equipment;

The possible pollution of the lubricant by the environment in which the equipment evolves;

The possible pollution of the lubricant by the process;

The cost/efficiency ratio;

A possible malfunction of the component detected by the maintenance or operating personnel;

The nature of the oil used (mineral or synthetic).

**The main parameters to be measured are:**

- Appearance;
- Water;
- Insolubles;
- Kinematic viscosity and viscosity index;
- Acid Number / TAN (Total Acid Number);
- Wear metals;
- Additive elements;
- Particulate matter index;
- Deaeration and foaming (turbines).

## V.III.5 PRECAUTIONS FOR BEST RESULTS

In order to make correct comparisons of results, it is necessary to ensure the representativeness of the samples through a suitable sampling method. For this, it is essential to respect the following precautions:

- Take a sample as homogeneous as possible, at the same place, ideally by the same operator, machine in operation or immediately after stopping.
- Preferably take the sample when hot, to avoid settling of insoluble products when cold.
- Take the sample, when possible in dynamic, just before the most fragile and expensive component.

- Do not collect the first sample at the purge, nor at the end of the draining. In the bottom of the return tank of a turbine, you could have water. When draining an engine, the thickest deposits are collected first, etc.
- Avoid collecting volumes of oil trapped in dead zones.
- Collect the sample directly in a clean container that is not likely to alter the composition of the sample provided by the laboratory.

In all cases, the best results in this area are obtained through close cooperation between the maintenance manager and technicians specializing in lubricant monitoring.

# IX. VIBRATION ANALYSIS FT

# IX. VIBRATION ANALYSIS

## IX.1 Introduction

A vibration is a movement described around an equilibrium position. For a rotating machine, this position often corresponds to the position of the machine at rest.

The external vibrations of the machine, once it is running, depend directly on the forces generated by the various internal elements in motion.

These forces are applied to the structure of the machine which responds (vibrates) according to its own characteristics. Thus, we can consider the vibrations as an image of the internal forces. (V = image of internal forces)

The intensity and the variation of these forces depend on the mechanical state of the machine, a monitoring of the vibrations will be an echo.

Like any motion, a vibration can be studied in terms of displacement, velocity (change in displacement per unit time) and acceleration (change in velocity per unit time).

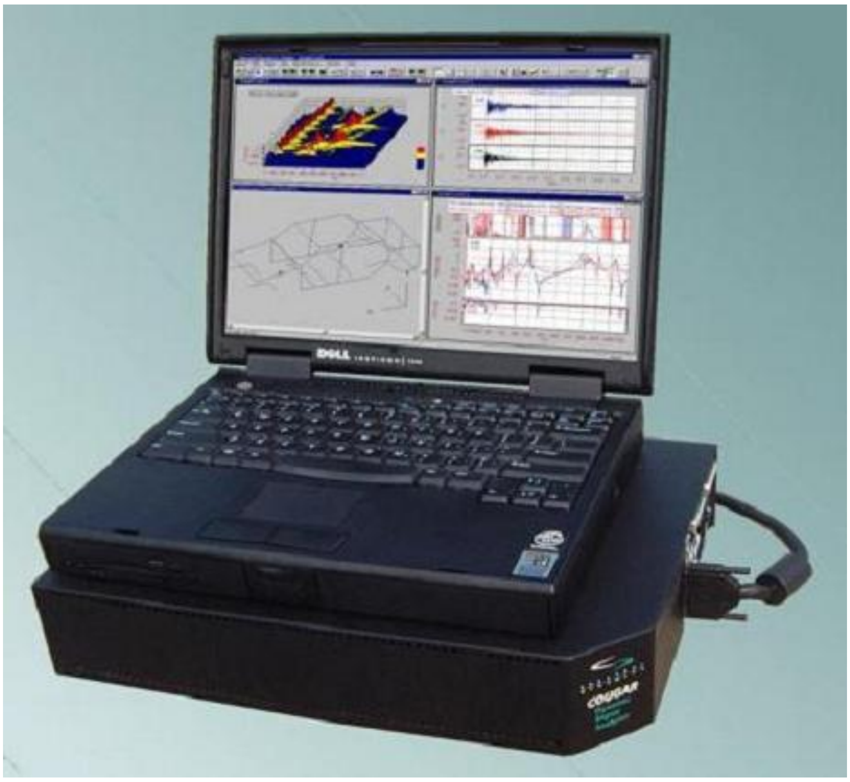


**Fig.IX.1 Vibrometer**

Any motion can be studied in terms of displacement, velocity or acceleration. When we consider a sine wave, therefore a single frequency, we can, knowing one of these quantities, calculate the others.

**IX.1 Displacement:**

The equation for the variation of displacement as a function of time can be written as follows:

**x(t) = A sin**wt

with : x : bearing displacement

**t :** time

**A :** amplitude

pulsation or angular velocity

- The period of this movement (here equal to one revolution of the rotor) is noted T is expressed in seconds (s).
- The inverse of the period, i.e. the frequency is noted f is expressed in Hertz (Hz).

is expressed in radian per second (rad/s).

We remind you that: **f = 1/T** et w **= 2π f = 2π / T**

**IX.2 Speed :**

The velocity of the vibratory movement corresponds to the variation of its displacement for a unit of time.

Mathematically, the velocity noted v is the derivative of the displacement with respect to time. It is written :

**v = dx/dt = d[A sin(**wt**)]/dt = A** w **cos(**wt**)**

## IX.3 Acceleration:

Acceleration is a change in velocity per unit time.

Mathematically, the acceleration noted γ is the derivative of the speed with respect to time. It is written :

γ **= dv/dt = d[A** w **cos(**wt**)]/dt = - A** w**2 sin(**wt**)**

These are three sinusoids, of the same frequency, but of different amplitudes and phases.

**Questions**

A tree rotates at a speed of 3000 revolutions/minute. Its clump creates a 20 μm displacement of the bearing.

a- What is the period of rotation of the shaft?

b- What is the period of the vibratory movement of the bearing?

c- What are the corresponding frequencies and pulses?

d- What are the acceleration and speed levels of this vibratory movement?

## IX.4 CHARACTERISTICS OF THE VIBRATION OF COMMON DEFECTS OF ROTARY MACHINES

Each defect in a machine produces a particular set of vibration components that can be used for identification. This section describes these vibration configurations for the most common machine defects. The descriptions provide the basic information needed to correlate the vibration components of the defects.

**Imbalance**

A rotor imbalance exists in all machines and is characterized by a sinusoidal vibration at a frequency of once per turn. The imbalance is usually the first to be questioned in case of excessive vibration at the rate of one turn, whereas this vibration can result from several different faults: misalignment, load variation, mechanical play, resonance...

**Bearing defects**

Bearings, or bearings with rolling elements, are the most common cause of breakdowns for small machines. Changes in the overall level are virtually unwavering in the early stages of deterioration. However, the particular vibration characteristics of bearings make vibration analysis an effective tool for both detection and analysis.

The specific frequencies that result from bearing defects depend on the defect, the geometric characteristics of the bearing and the speed of rotation.

Software supplied by bearing manufacturers calculates the expected frequencies.

**Lineage defect**

Vibration due to misalignment is usually characterized by a component double the operating speed and high axial levels.

A misalignment takes two fundamental forms:

- A preload resulting from a curved shaft or bearing incorrectly placed;
- Misalignment of machine shafts of the same train.

**Mechanical games**

The mechanical play usually manifests in bearings frames or caps and always produces a large number of harmonics in the vibration spectrum. The play tends to produce a directional vibration, which is a useful feature for the different rotation defects such as imbalance.

Belt transmissions present a situation in which a set does not reveal a large number of harmonics

**Gear failure**

Gear problems are characterized by vibration spectra that are easy to recognize but difficult to interpret. The difficulty is due to two factors:

It is often difficult to mount the transducer close to the problem;

The number of vibration sources in a multi-gear transmission leads to a complex combination of gearing frequencies of the toothed wheels.

Basic spectra found when the gear is in good condition facilitate the identification of new components or components whose level has changed significantly.

**Blade defect**

Blade problems are usually characterized by a high fundamental vibration or by a large number of harmonics in the vicinity of the blade pass frequency. Some components of the pass frequency (number of blades x speed) are always present and the levels can vary considerably with the load. This is especially true for fast machines and makes critical the work of recording operating parameters for obtaining historical data. It is very useful in the analysis phase to have basic spectra for several levels of operation.

**Resonances**

Resonance problems arise when the natural frequencies of the shaft, machine housing or associated structure are excited by the operating speed (or harmonics thereof).

These problems can usually be easily identified by the fact that the levels decrease considerably when the operating speed is increased or decreased.

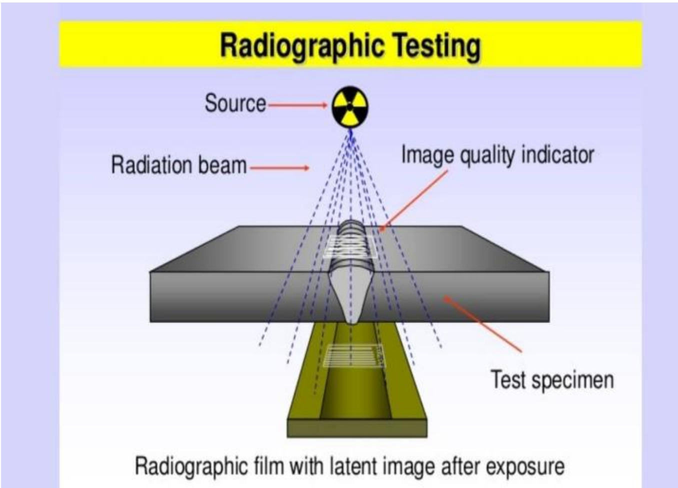
# X. X-ray RT

# X. X-ray

## X.1 Introduction;

Radiography uses sources that emit ionizing radiation. These radiations have a very high energy that allows them to pass through matter.

When crossing the material, the possible defects contained in it constitute obstacles that absorb less radiation. The differences in absorption can be either visualized on a fluorescent screen (for example: radiography used in the medical field), or recorded on a special film (industrial radiography case).



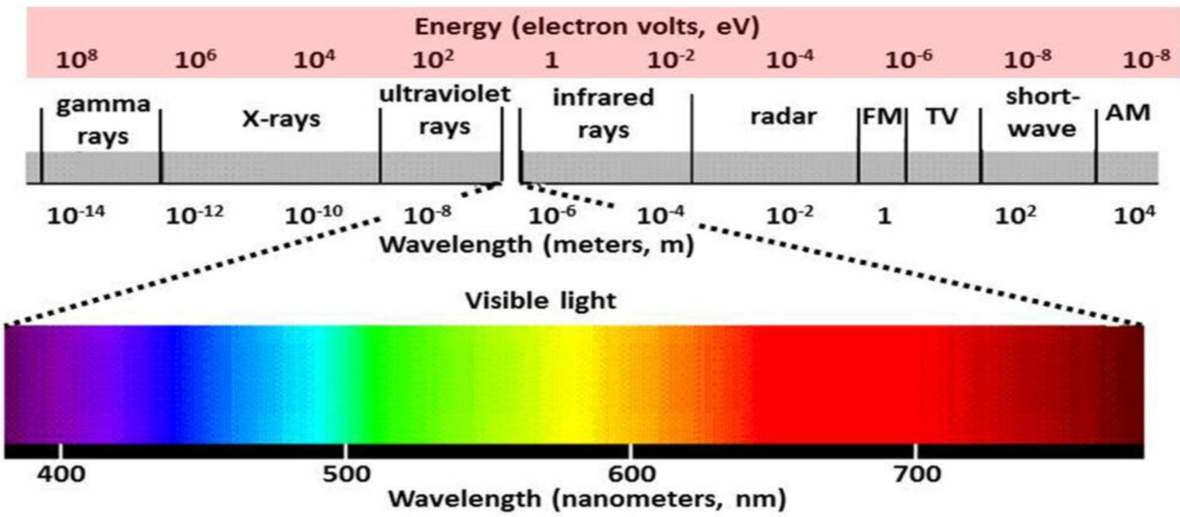




**Fig. X.1 Electromagnetic Radiation**

The part is placed between the radiation source and the film.

• The denser the material, the more radiation it absorbs.

• The film gray intensity is proportional to the radiation intensity.

**LAWS OF PROPAGATION OF IONIZING RADIATION**

This control mode uses low wavelength electromagnetic radiation (order of magnitude angström) to pass through light-opaque materials.
Nature and main properties
The X-rays or γ which are used in control have the following properties:
They propagate in a straight line at the speed of light.
They are invisible.
They pass through matter and are partially absorbed during transmission.
They can damage or destroy living cells.
They ionize the gaseous media.

## X.2 IMPLEMENTATION

X-ray inspection requires an appropriate selection of equipment, procedure and examination conditions. In fact, to obtain a sharp and contrasting image to reveal the desired defects, one must follow certain steps:

- ✓ The radiation, and thus the source, must be of sufficient power to be able to cross the room without degrading the contrast related to the scattered radiation. The intensity of this radiation, that is, the activity of the source, will be chosen as much as possible to reduce exposure times while limiting geometric blurring.
- ✓ The shot must be defined in terms of geometric conditions, position and relative orientation of the source, object and film. The use of a number of accessories can improve the results for example: lead diaphragm, filters placed in front or behind the object, not to mention the reinforcing screens which are radiation converters to improve the sensitivity of the film.
- ✓ The choice of film also results from a compromise between speed of printing and resolution, in view of the type of defect sought and the conditions of shooting. The determination of the exposure time is done in practice by means of charts taking into account the parameters of the source and the conditions of shooting. The exploitation

of the clichés is done, after development, fixing (fixing: process of in sensitization to the light of an image by removal of the silver salts, after development) and washing,

by examination of the film by transparency on standard light boxes. The view boxes, designed so that the luminance emerging from the image is of the order of 100 cd/m2, which requires special devices for the examination of high-density optical images. The reliability of the examinassions is related to the visual acuity of the observer, which is itself a function of his vision but also of the optical conditions present.

The quality control of the radiographs is essential in order to be able to draw conclusions on the quality of the part itself, because it allows to know if the shot was taken in good conditions, compatible with the sensitivity sought for the examination.
Several means may be used: in addition to the reference to a photograph taken on an identical part with known natural or artificial defects, the I.Q.I. image quality indicators technique is very commonly used. It is a small piece that is applied to the source side metal, composed of steps with small holes of diameters equal to the thicknesses distributed in geometric progression, according to the standard I.Q.I in France. These indicators provide overall qualitative information on the results obtained. Finally, it should be noted that it is imperative to identify and locate radiograms by means of figures or letters of lead alloy arranged on the part under examination.

**Radiographic film**

The films consist of a plastic support covered on both sides with an emulsion of silver halide salts in a layer of gelatin.
One of the characteristics of films is the size of the grain. Coarse-grained films are faster than fine-grained films but the definition of images is lower.

**Defect visibility**

This defect visibility is determined by the following factors:
The nature and thickness crossed by the radiation of the defect;
Geometric factors (distance of the focal spot from the source to the film for example) which will condition the sharpness of the default contours (blurring problem);
The properties of the film (granulation, base veil, presence of filter screens and/or enhancers);
The quality of the radiation used.

**Quality of control**

To appreciate the quality of the X-ray image, it must be translated into digital form.
Image Quality Indicators (IQIs) are used. They are placed in contact with the room facing the radiation source. The IQI image on the film will reflect the image quality.
The main IQIs used are:
Wire indicators (used in most European countries);
Drilled step indicators (used mainly in France);
Platelet indicators (used in the USA).

**Protection**

The use of a radiation source requires compliance with the safety regulations of the control operators.

**CONTROL PROCEDURE**

The development of an X-ray control requires the choice:

- Anode voltage;
- Cathode current;
- Distance from film to focus;
- Film type and possibly reinforcing screens;
- Exposure time.

The determination of the exposure time valid for:
A given material;
A domain of tension;
A distance from the film to the focus;
A type of film and reinforcing screen

## X.3 APPLICATIONS

Search for internal anomalies:

a) Moulded parts: rebates, cracks, remnants of nuclei, etc.

b) Welds: cracks, melts, lack of penetration, blows, inclusions, shape defects;

c) Piping: internal corrosion or erosion, internal deposits, weld defects;

d) Reinforced concrete walls: cavities, cracks, reinforcements;

e) Valve position in a valve;

f) Control of games in a nested assembly;

g) Checking a blind assembly.

**Benefits**

• Detection of surface or volume defects in all materials;
• X energies available: from a few Kev up to 15 Mev;
• Ability to X-ray complex shapes and steel thicknesses ranging from a few micrometers to 600 mm;
• Sizing and possible identification of defects;
• Very high fault detection sensitivity for some techniques;
• Detection sensitivity in the order of a few µm with magnification;
• Possible real-time examination (fluoroscopy);
• No dead zone below the surface;
• Radiograms can be stored for decades;
• Transportability (low energy X-ray generators, portable gamma-ray x-ray equipment of approximately 20 kg).

**Disadvantages**

• Fault detection sensitivity depends on the size of the source and its energy, the position and orientation of the defects in the part, the thickness of the part, the sensitivity of the film...

• Difficulty locating defects in depth;

• High operating costs (radiation sources, equipment maintenance, X-ray films, mandatory controls, radiation protection...);

• Radiogram interpretation is often difficult and requires high level operator training and extensive experience.

**Disadvantages in Health and Safety**

• The radiation used is dangerous and can cause serious occupational diseases;

• Operators are classified as Category A workers and wear an individual dosimeter;

• Regulations are often very restrictive (transport and storage of radioactive sources, declarations, authorizations, women’s work...).

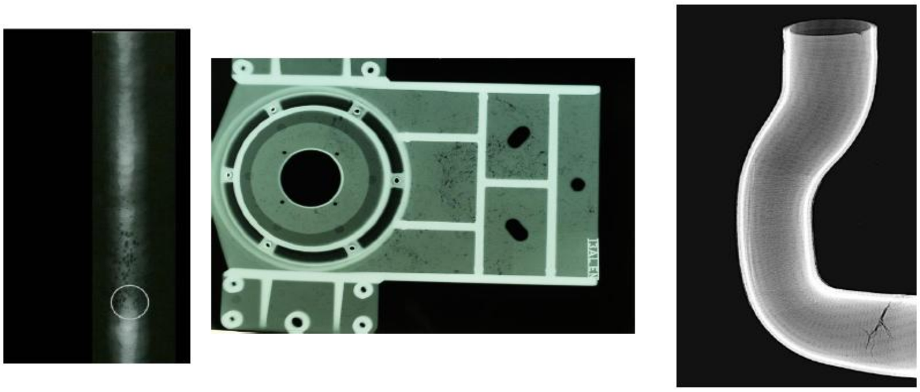


Fig. X.2 Results Radiography

## X.4 TOMOGRAPHY

Born in the 1970s for the medical field tomography has today adapted its parameters to the industrial field whose all sectors can benefit from the possibilities, be it in aeronautics, in the automotive sector, foundry, mining, oil and agri-food industries.

X-ray tomography is used in production, in prototyping or in the development of manufacturing processes. The improvements made to this technique today concern high and very high resolution and three-dimensional reconstruction.

This technique allows you to reconstruct the volume of an object from a series of measurements made per slice from the outside of that object. In a high-resolution version, it is also increasingly used in materials science and NDT non-destructive testing.

**TOMOGRAPHY PRINCIPLE**

Tomography (cross-section imaging) is a technique that consists of reconstructing the volume of an object (the human body in the case of medical imaging, a geological structure in the case of geophysics) from a series of measurements that have been moved outside the object. These measurements can be made at the same surface or at a certain distance. The result is a reconstruction of certain properties of the inside of the object, depending on the type of information provided by the sensors (particle capture, sound pressure, attenuation of a light beam, difference in speed or polarization of seismic waves, etc.).

Tomography, mathematically speaking, breaks down into two stages. First of all it requires the development of a direct model, describing sufficiently accurately the physical phenomena as measured. Then, we determine the inverse model or reconstruction used to find the three-dimensional distribution based on the direct model.

The 3D X-ray tomography system to obtain the 3D volume of a plastic, metal or composite part.

Placed on a 360° turntable, the room undergoes an X-ray scan in its waterproof cabin. This technique, which relies on tomography, will also make it possible to detect microfissures, air bubbles, reassures or welding lines, including on small parts.

Generating 3D images by tomography requires the acquisition of a series of two-dimensional X-ray images (radiographs) during a progressive rotation of the sample, step by step through 360° (increments less than 1° per step). These projections contain the position and density information inside the object. This data accumulation is then used to digitally reconstruct the volume data.

**TOMOGRAPHY UTILITY**

X-ray tomography therefore allows access to the core of matter to assess variations in radiological absorptions and differences in composition.

It also makes it possible to locate very finely any heterogeneity, singularity, vacuum or inclusion present in an object, as well as to verify the assembly and positioning of complex mechanical assemblies.

Finally, when the scan times are compatible with the speeds of certain physical phenomena, tomography can lead to dynamic measurements to follow, for example, the evolution of a material under stress.

**AREAS OF APPLICATION**

A wide variety of areas of application of tomography in the industry:

- Aeronautics;
- The metallurgy of powders;
- The automotive sector;
- The armament;
- Composite and plastic materials;
- The archaeology;
- The life sciences;

- The petrochemical industry;
- Agribusiness.

**Benefits**

• Complementarity with conventional radiography;

• Digital images provide quantitative parameters that are inaccessible to other NDT methods;

• Tomography allows you to analyze the material at the heart of objects directly without altering them, thereby eliminating the problem of sample representativeness.

A recent non-destructive testing technique from the medical field where it has revolutionized diagnostic aids by supplementing the overall information of projection radiography with its precise internal local data acquired on virtual slices, Today, tomography is a reliable tool, although still uncommon compared to other NDT techniques used, but it is applied to a wide range of industrial sectors.

Faced with the diversity of materials, the diversity of tasks that often lead to the implementation of heavy equipment and still expensive especially for SMEs and SMIs, tomography has however seen in recent years develop in the industrial landscape, thanks to its speed in producing images representative of the internal structure of objects, a tomographic thought that even today passes through a reflection of normalization of controls.

Although it is still very small compared to the park of facilities working in the medical field, this industrial park offers a great diversity of functionalities from low energy to very high energy...

**Disadvantages**

The main difficulties associated with the method are due to:

• The extreme variety of equipment and its modes of operation;

• The wide variety of controllable materials;

• The wide variety of objectives sought.

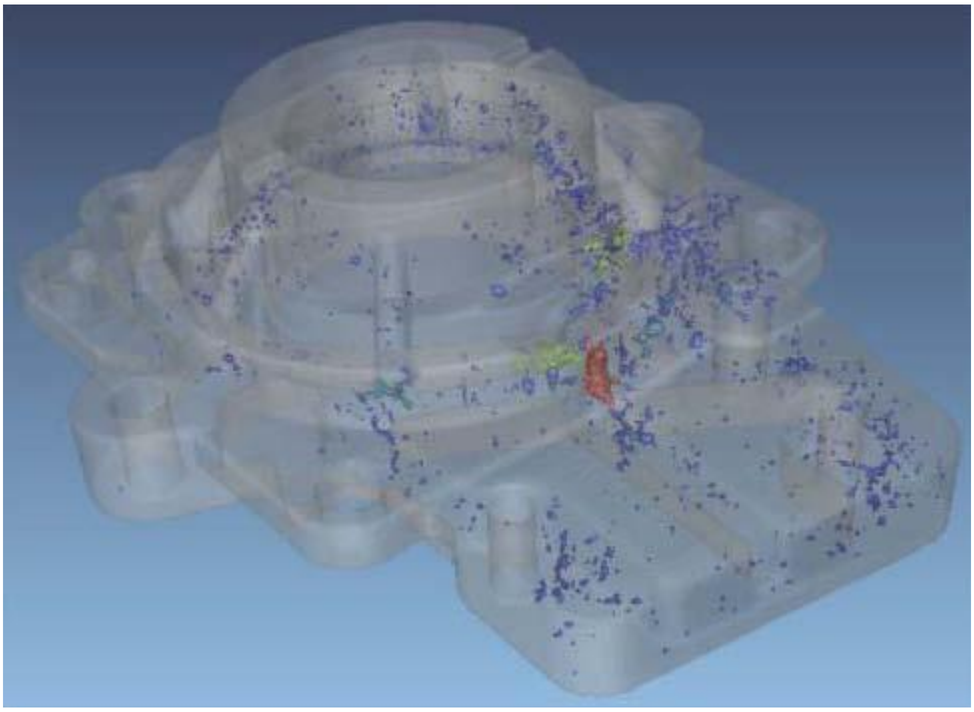


**Fig. X.3 Example Metallurgy: analysis of the porosity of an aluminium casting**

# <u>XI. Acoustic Emission AE</u>

# XI. Acoustic Emission

## X1.1 Introduction

The technique of Non-Destructive Testing by Acoustic Emission consists in detecting ultrasonic waves emitted by the noise generated during the evolution of a degradation.

**Fig.XI.1 Principle of acoustic emission**

### *XI.2 Principle*

Acoustic emission is a phenomenon of energy release in the form of transient elastic waves resulting from local micro-displacements internal to a material (cracks, inclusions, corrosion, delamination, etc.). This phenomenon manifests itself in many materials when they are subjected to mechanical, thermal or chemical stresses. The application of a load and/or the presence of an aggressive environment produces internal modifications such as the evolution of cracks, local plastic deformations, corrosion and, in certain cases, phase transformations which generate the acoustic emission. This gives, therefore, some information on the internal behavior of the materials considered. The waves propagate in the structure then are detected by means of specific sensors which allow the conversion of the surface movements of the material into electrical signals. These signals are processed by appropriate instrumentation in order to indicate and locate the sources of acoustic emission.

## XI.3 Mode of examination

The measurement of the acoustic emission generated by a structure subjected to stress can be described in two phases: - Acoustic wave detection: Detection is generally ensured by piezoelectric sensors allowing the conversion of the acoustic wave into an electrical signal. The acoustic emission signal is then conditioned by a preamplifier which provides electrical impedance matching, amplification and filtering. The acoustic emission signal is then transmitted to the measurement system which allows the digitization, the recording of the waveforms in real time and/or the extraction of a certain number of parameters relating to the signals. The acoustic emission can be continuous or discrete. The discrete acoustic emission signal called burst has the general appearance of a damped sinusoid. - Analysis of real-time and delayed acoustic emission data: Once the acoustic emission data has been stored, appropriate processing is applied in order to evaluate the results of the measurements. This processing relates to the parameters of the bursts (historical and statistical analyses), but also makes it possible to group the bursts detected by the various measurement channels to locate the sources of acoustic emission. As with other test methods, the personnel required for the services, the performance of the tests and the interpretation of the results must have the corresponding training and experience in the field of acoustic emission testing. These qualification and certification requirements are specified in standard NF EN ISO 9712.

## XI.4 Fields of application

The fields of application of acoustic emission are multiple: - Checking the integrity of pressure equipment. Acoustic emission is an alternative to hydraulic testing for the requalification of pressure equipment; - control of industrial structures such as nuclear reactors; - online control of materials manufacturing processes; - monitoring of installations in operation; - detection of leaks; - corrosion detection; - research and development; - applicable on many materials (steels, composites, ceramics, etc.).

## XI.5 Interests of the method

Acoustic emission has many advantages, including: - The overall control of the structure (volume); - detection and location of evolving faults; - real-time dynamic control under service or load conditions; - diagnosis of the severity of the damage; - monitoring over time; - the prevention of industrial risks; - control of structures in service; - the minimization of the time of intervention and immobilization of the installations.

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