Digital Training for European Welding Inspectors

Module 2

Testing of welds and reporting

D-EWI

Digital Training for European Welding Inspectors

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2.1. Destructive Testing of Welded Joints

Destructive tests are known as such, as opposed to non-destructive tests, in which the sample or element to be inspected is not damaged after the test has been carried out. In this type of test, the sample or element is damaged, altered or unusable for further use. Therefore, it is not possible to test 100% of a manufacturing batch by means of this type of test. However, it is often necessary to "sacrifice" some parts or samples of a batch, since, through this type of test, we obtain information or characteristics of the parts that we can only obtain through them.

The behaviour of metallic materials can vary widely depending on their chemical composition, heat treatment, working and surface conditions, presence of discontinuities, etc.

The analysis of the mechanical properties of materials, welds and welded joints is carried out by means of tests that allow us to check that they have the appropriate characteristics for use in parts and components. The tests also allow precise comparisons to be made with data obtained from similar tests on other materials, enabling the most suitable material to be selected for each application. Regardless of the test that needs to be carried out, it is of the utmost importance that it is performed under pre-established conditions and that these are recorded together with the results, in order to guarantee the reliability of the data obtained, as well as the reproducibility of these data when carried out by different bodies.

The tests are normally carried out on specimens called longitudinal specimens, the largest dimension of which coincides with the direction of lamination, extrusion or main deformation of the material to be tested. However, on certain occasions, they are required to be carried out on specimens obtained in a direction perpendicular to the previous one, in this case they are called transversal.

In general there is little difference between the tensile properties obtained with longitudinal or transverse specimens, although transverse specimens tend to give slightly lower ductility values than longitudinal specimens. In some cases, tests may be required on specimens taken in the thickness direction, perpendicular to the rolling plane, which are even more heterogeneous than the above.

It is usual to classify the mechanical properties of metals into two main groups: those related to **strength**, which measure the material's ability to withstand static loads, and those related to **ductility**, which, on the one hand, govern to a large extent its ability to withstand dynamic loads without breaking and, on the other, its ability to accept, without cracking or breaking, the plastic deformation required in certain forming processes. Generally speaking, it can be stated that those treatments which improve the strength of a metal reduce its ductility, so that the properties included in the two groups mentioned above vary in opposite directions.

Mechanical tests are **destructive tests**. This carries with it the danger of assuming that untested materials are the same as those that were tested. If a bar is tensile tested or a welded joint is sectioned to examine its quality, checking for discontinuities, penetration, etc., we can only assume that the rest of the bar or part of the weld not tested has similar properties to those tested, because it was made under the same conditions.

However, destructive testing allows for an intensive study of the material under examination, and much more information can be gathered than that obtained by any non-destructive technique. On the other hand, destructive testing **allows materials to be tested under the same conditions that they will have to withstand in practice**, and the test can be related to a product, a process or both. Destructive testing can be time-consuming and costly, due to the need to prepare and test samples in sufficient quantity for the results to be statistically representative of the material properties.

In this topic, the test methods that are most generally applied to determine the possible future behaviour of welded joints will be presented. These material tests are generally required, and fully defined, in their corresponding quality specifications and we refer the reader to them. This does not mean that the Welded Construction Inspector should not be able to interpret the quality specifications of the materials whose welds are to be inspected. In the same way, he must be sure that the material tests carried out have been the appropriate ones in each case.

Tensile, hardness and bending tests are the most frequently used tests to determine the breaking strength and ductility of a material. The welding process modifies the metallurgical structure, and it is important to know the effect of these changes on the mechanical properties. Therefore, these tests can indicate the most important characteristics of a welded joint, and are also used to qualify welding procedures and welders as required by most codes.

A summary of the mechanical properties of the steels and the tests by which their parameters are determined is given in the following table.

Table 1: Mechanical properties of steels

Technological property	Characteristic parameter	Characterisation test
Mechanical strength	Elastic yield strength	Tensile test
Stiffness	Modulus of elasticity	
Ductility	Percentage elongation at break	
Toughness	Modulus of toughness	
Impact resistance	Resilience	Impact bending test
Hardness	Hardness	Hardness test
Fatigue resistance	Fatigue limit	Fatigue test
Resistance to thermal creep	Thermofluence limit	Thermofluence test

2.1.1. Tensile test

The tensile test consists of subjecting a specimen, of standardised shape and dimensions, to an axial tensile force which increases slowly and gradually until the specimen breaks. During the test there is equilibrium between the force applied to the specimen and the reaction of the specimen. Under these conditions the specimen is under static load.

Because of the information obtained from this test, it is probably the most important mechanical test that can be performed on a material. The tensile test is simple, fast, applicable to all types of materials, relatively inexpensive and fully standardised.

During the test, certain properties of the material are measured which provide information on its ability to withstand static loads (strength) and on its deformability (ductility).

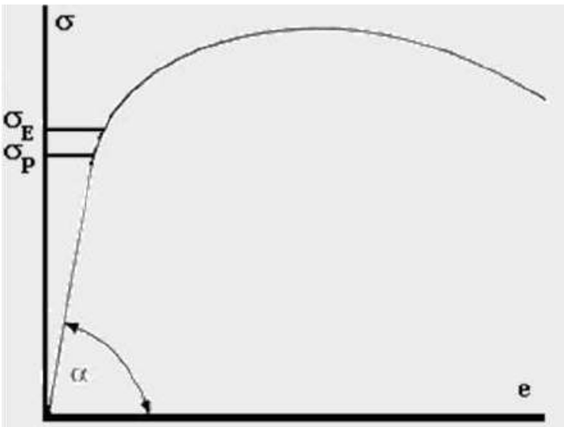


Figure 1 - Apparent stress-strain curve

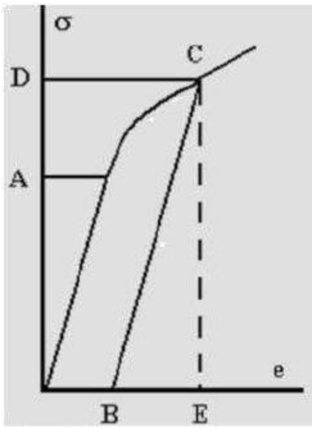


Figure 2 - Determination of the yield strength 0.2%

The conventional yield stress is the stress that produces a permanent deformation ε=0.002 (0.2%) in the material. It is easily determined on the tensile curve by taking a segment OB = 0.2 (figure 2) on the strain scale, generally expressed in percent, and drawing a parallel to the straight section through B, which cuts the curve at a point C, whose ordinate OD is the conventional yield stress. The justification for this construction lies in the fact that, if once the stress OD is reached in the test, the material is unloaded very slowly, the line that relates stresses and strains during unloading coincides with the straight line CB and, when the load is zero, there remains a remaining strain of a value given by the segment OB. It can therefore be seen that, of the maximum deformation reached by the specimen, equal to OE, the BE part is elastic, since it disappears with the load, and the OB part is plastic. If we were to reload the specimen again (which already shows a plastic deformation OB), we would observe that the new tensile curve has a straight section up to approximately point C, whereas the first one was only straight up to approximately point A. This means that the plastic deformation of the material has increased its strength by raising the yield strength from approximately A to C. This phenomenon is known as strain hardening.

Breaking strain

In very brittle materials, breakage occurs without macroscopically observable plastic deformation, i.e. these materials break without leaving the elastic zone. Their tensile curve will therefore be as in figure 3A. The stress σ_E is both that which produces the maximum elastic deformation, i.e. the elastic limit, and that which causes the rupture, or breaking stress, represented by σ_R. It is therefore, in this case:

$$\sigma_R = \sigma_E$$ *Equation 1*

In materials with very low ductility the conventional tensile curve is as in figure 3B. When the stress on the material exceeds its elastic limit, plastic deformation begins and with it the strain hardening of the material, so that for the deformation to increase, the stress must increase. The curve thus follows an upward course until, when the stress reaches a value of $\sigma = \sigma_R$, the material breaks. The value σ_R is now the breaking strain.

If the material is ductile, its tensile curve will take one of the forms shown in figures 3C, 3D or 3E. On exceeding the yield stress, or the values corresponding to the yield phenomenon, the curve rises as in the previous case and reaches a maximum value and then falls until failure occurs. The maximum tensile force on the specimen, divided by the area of its initial section S_0, is called the breaking stress σ_R and has the following value:

$$\sigma_R = \frac{F_{max}}{S_o}$$

Equation 2

The breaking strain of ductile materials does not represent any property of the material. The extensive use that has been made of it is justified only by the simplicity of its measurement and because, being always equal to or less than the real breaking strain, when it is used as a reference for the strength of the material, we are on the side of safety.

However, it is nowadays preferred to measure the strength of a material by its yield strength, which is a physical characteristic. Also, as materials usually have to work within the elastic behaviour, the allowable stress σ_t is set as a fraction of the yield strength:

$$\sigma_t = \frac{\sigma_E}{K}$$

Equation 3

where K is a safety coefficient representing the actual range between the working stress and the stress at which the material would begin to undergo permanent deformation.

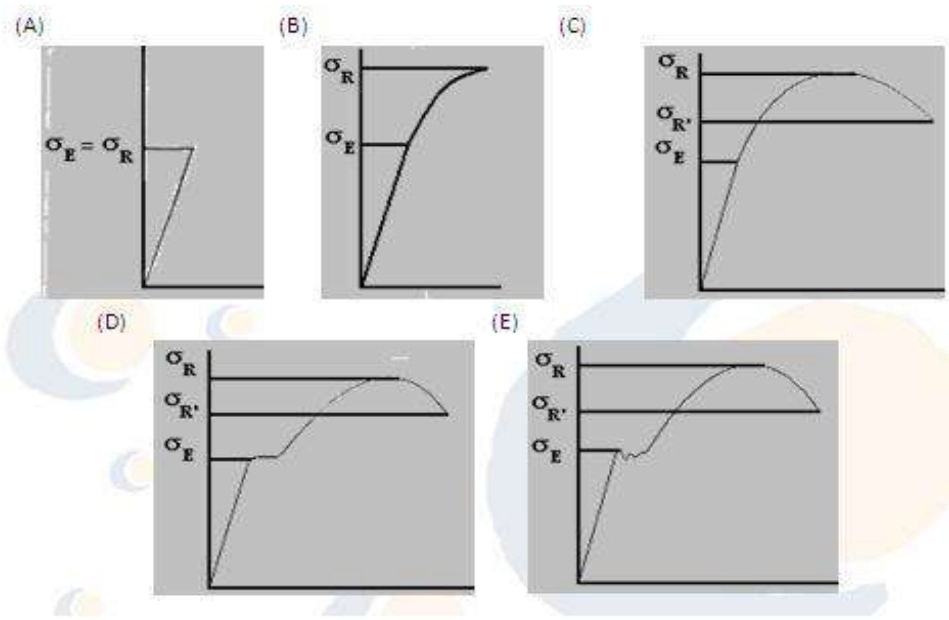


Figure 3 - Stress-strain curves with different degrees of deformation in the tensile test

Elongation

Deformation, or unit elongation, was previously defined as:

$$\varepsilon = \frac{L - L_o}{L_o}$$ *Equation 4*

Where L_o is the initial length of the specimen and L is the final length of the specimen after breakage, which is measured by joining the two resulting pieces.

If expressed as a percentage, we have the elongation:

$$A = \frac{L - L_o}{L_o}$$ *Equation 5*

Elongation represents the maximum unit plastic extension that the metal can withstand before breaking. It is therefore a property linked to deformability, i.e. a ductile characteristic.

Striction

Once the tensile specimen is rotated, the area of the broken section is S_R. The quotient is called the section reduction ratio:

$$q = \frac{S_o - S_R}{S_o}$$ *Equation 6*

and we call the value striction:

$$Z = \frac{S_o - S_R}{S_o} x100 = 100q$$ *Equation 7*

If, during the test as a whole, the material undergoes a high permanent elongation at break, A, and a pronounced strain, Z, its behaviour is said to be "ductile". If, on the other hand, failure occurs without the material undergoing a macroscopically appreciable plastic deformation, its behaviour is considered to be 'brittle'.

Transverse butt weld joint test

The specimens are removed from the material in such a way that the weld is arranged perpendicular to the direction of traction. They involve the filler metal, the heat affected zone and the base metal.

When these specimens are broken, they may break at the base metal, which tells us that the strength of the weld is above the breaking load of the base metal, but tells us nothing about the ductility of the welded joint. If the specimen breaks at the weld, it means that most of the total deformation has occurred in this area. As these breaks give low elongation results over the total of the specimen, we do not obtain a result that reflects the ductility of the welded joint. For the same reason, in this case, a comparable and reliable value of the elastic limit is not obtained either, due to the fact that this value is defined as a function of the uniform deformation that occurs along the entire length of the material being tested.

Therefore, this type of test is only valid to determine the tensile strength of the weld and to evaluate its "performance" in terms of strength only. In this sense, different codes require them for the qualifications of welding procedures, indicating that only the breaking load values obtained and the zone in which the breakage occurs are reflected.

<u>Overlap welded joint test</u>

In this type of joint, the aim is to determine the resistance of the weld to shearing or shearing of a given joint. For this reason, the specimens are usually prepared in such a way that they are representative of the joint to be tested, following procedures similar to those that will be applied during their manufacture. See figure 4.

With this test we obtain the breaking load Fm at which the joint collapses. With the breaking load and the area of rupture A_t we obtain the breaking stress σ_R (F_m/A_t) expressed in MPa and oriented to the bead throat; and with the breaking load and the length of the bead b, we obtain the load per unit length (F_m/b) expressed in N/mm and applied to the weld bead.

These specimens are quite sensitive to the procedures used during their production. Gaps between overlapping parts can lead to stress concentrations at the root of the welds and thus produce non-homogeneous and non-comparable results.

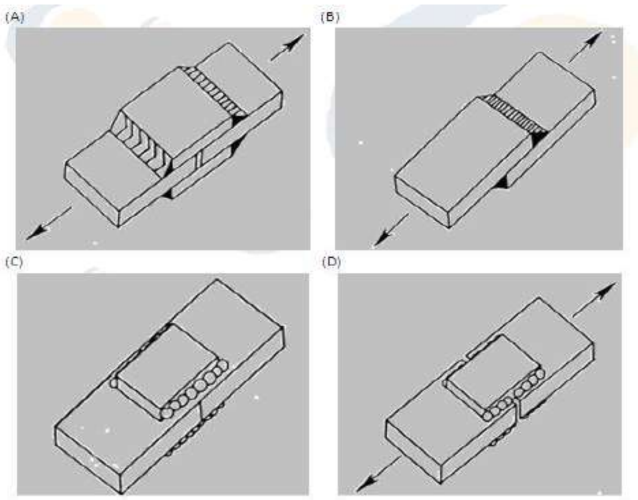


Figure 4 - Specimens for testing overlap joints

2.1.2. Bend test

The bending tests are carried out by bending the specimen until it is bent at a certain angle, so that its outer face is subjected to high tensile stresses and its inner face to compressive stresses.

This test measures the minimum radius at which it is able to bend without cracking, i.e. **it measures the deformation capacity of the stretched area.**

Depending on the applicable standard, a certain bending angle may be required without cracks appearing or, more frequently, a 180° bend (parallel faces) without cracks exceeding a certain value.

This is a very demanding test to measure the ductility of the material in the area subjected to bending. It is often used to assess the deformation capacity or to detect possible anomalies in an area such as embrittlement due to localised heating and cooling during the welding process.

Measurable parameters

The measurement of ductility is carried out in the tensile test by means of the elongation, which determines the general ductility of the material as a whole, and by means of the striction, which determines the localised ductility in the fracture zone. However, in this test it is not possible to determine whether there are embrittled sections in the specimen. This is why the bending test is necessary to confirm this ductility.

Since ductility is defined as the measure of the plastic deformation that the material can withstand before breaking, the test is performed by bending the specimen at a given curvature until the two branches of the specimen are parallel or at a given angle.

When the specimen is bent, its outer face is subjected to traction, according to the law shown in figure 14, and must be observed during the test in order to be able to appreciate the possible formation of cracks that would correspond to a breakage of the material by traction.

Bend test on welded joints and information supplied

There are different types of bend tests used to evaluate the ductility and detect the possible presence of defects in welded joints. The specimens can be longitudinal or transverse to the axis of the weld and are subjected to bending using tools that allow them freedom of movement, free bending, or that limit deformation, if this is directed or guided.

Depending on the surfaces exposed to the maximum elongation, this weld test is called face, root and side bending. Figures 5 and 6 illustrate these types of tests.

Tests with transverse specimens are normally used to qualify operators, because, in this way, possible defects in execution that are not revealed by the tensile test are usually revealed. It should not be forgotten that, as with transverse tensile specimens, the bending shape may be different, depending on the different bending properties of the different parts that make up the specimen.

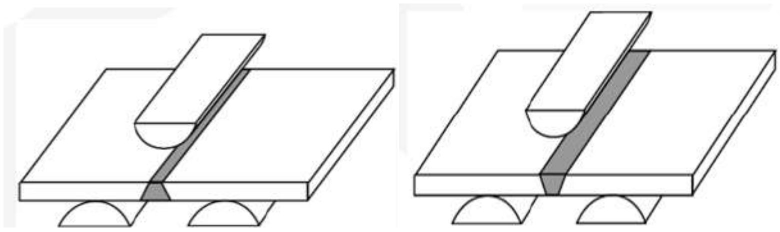


Figure 5: Face bend test (left image) and root bend test (right image)

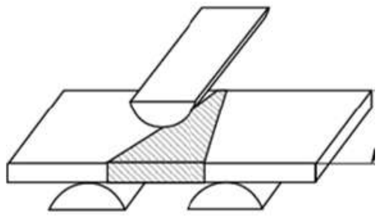


Figure 5 - Lateral bend test

2.1.3. Fracture test

Fracture or breakage is the fragmentation or division of a solid into two or more parts. Fracture thus leads to the creation of new surfaces, which we call fracture surfaces, to which a certain energy is associated. Therefore, the production of a fracture requires the contribution of a certain amount of energy supplied by the forces applied or by those coming from an external field. In any case, the fracture phenomenon consists of the initiation of a crack or fissure and its propagation through the solid to rupture. This process can take place in a single step, or a small crack may be generated first and grow slowly (stable growth), until it reaches a sufficiently large size and propagates abruptly, causing the component to rupture (unstable growth).

Detectable imperfections

This test allows us to carry out a visual inspection inside the material after breakage. In this way, we can detect discontinuities such as porosity, metallic inclusions, lack of penetration and lack of fusion.

Fracture testing of welded joints

The type of test shown in Figure 7 is used to determine the quality of the fillet weld. The base metals, filler metals and welding procedure used should be the same as those subsequently used in the structure or equipment under study. This test is also used to qualify welders.

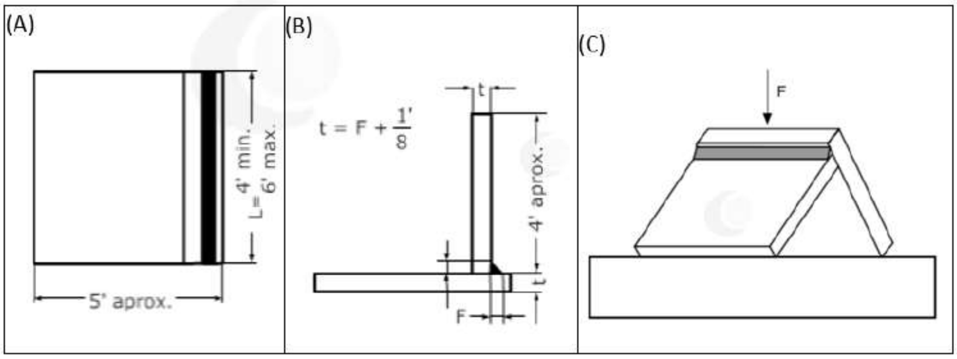


Figure 6 - Fillet weld joint fracture tests

A force F, as shown in the figure, is applied until breakage is achieved, the fracture surfaces are then examined and their state of toughness or brittleness assessed.

2.1.4. Hardness test

Hardness is a property of materials that identifies the behaviour of their surface when in-teracting with other materials. The hardness characteristics of a weld can be used independently or as a complement to tensile and bend tests.

The main methods used are based either on the study of the surface of an imprint produced in the area to be studied (Brinell, Vickers and Knoop hardnesses) or on the depth of the imprint (Rockwell hardness).

Information provided by the test

The results of hardness tests provide us with information on the metallurgical modifications caused by welding. For example, if the cooling to which a weld of oils normally used in construction is subjected is very rapid, hard tempering structures can be formed. Therefore, by investigating the hardness obtained in the filler metal and thermally affected zones, we can find out if we obtain the precise ductility conditions. On the other hand, welds of cold-worked or age-hardened materials can give hardness values in the heat affected zones that are considerably lower than those of the base materials. This indicates that the data obtained from these tests are affected by the welding variables such as: process used, state of the base materials, heat input, preheating, temperature between passes, composition of the input material and thickness of the joint. Therefore, the hardness values can tell us how these variables have been used.

Excessive hardness in the weld seam or in the affected area indicates the presence of brittle structures, with a consequent loss of ductility. It is also an indication of the risk of cracking.

In summary, it can be said that hardness testing is very useful to know with a good approximation the ductility characteristics of the joint and to predict its strength properties. It is also a very versatile and generally low-cost test. It should be carried out under standardised conditions and, if necessary, complemented with other tests so that, between the two, they bring us closer to reality.

Brinell hardness

It uses an indenter consisting of a 10 mm diameter steel ball, which is compressed against the surface of the sample by a force of 3.000 kg. The hardness value is calculated from the measurement of the diameter of the indent, and is equal to the quotient of dividing the load F by the surface of the indent considered as a spherical cap. Brinell hardness is designated by HB (Brinell Hardness).

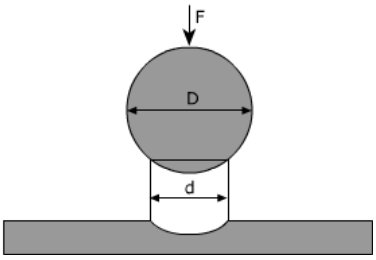


Figure 7 - Geometry of the footprint produced during Brinell test

Vickers hardness

It uses as a penetrator a diamond pyramid with a square base in which the opposite faces form a dihedral angle of 136° ± 1 (See figure 9). The Vickers hardness (HV) is obtained by dividing the load in kg by the true surface of the indentation in mm.

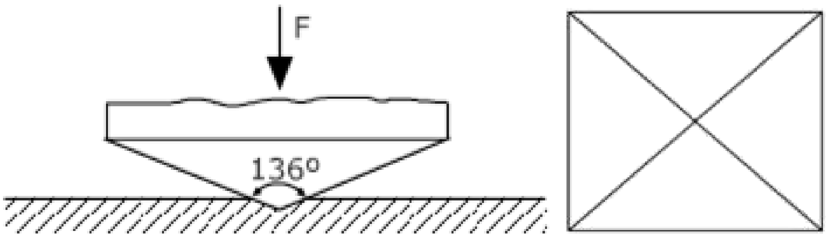


Figure 8 - Geometry of the footprint produced during the Vickers test

Rockwell hardness

The Rockwell test is specially designed for hard materials that cannot be adequately tested by the Brinell method. The Rockwell test uses alternatively a diamond conical indenter or a spherical steel indenter, the diameter of which can be 1/16", 1/8", 1/4" or 1/2". The conical indenter has an angle at the apex of 120° and the tip is rounded with a radius of 0,2 mm.

For high hardness workpieces, the diamond cone is used as the penetrating body and the hardnesses obtained are called Rockwell-C (HRC). For soft materials, the 1/16" hardened steel ball is used and the hardnesses obtained are called Rockwell-B (HRB).

Microhardness or Knoop Hardness

Hardness measurements are sometimes required on very small surfaces, such as when the hardness of certain micro-constituents, the hardness of very small parts such as clockwork gears or when determining the hardness gradient in a cemented layer or in a weld seam. Diamond indenters with loads ranging from 25 to 1000 g are used for this purpose. Larger loads are used for macroscopic measurements, while smaller loads are used to determine the hardness of phases or micro-constituents. The most commonly used system is that using a Vickers indenter, similar in geometry to that used in the hardness tests described above, but adapted to a metallographic microscope which allows the size of the micro-indent produced on the tested material to be measured.

The hardness obtained is obtained as a function of the size of the indentation produced and the indentation load applied. The formula applied to determine the Vickers hardness value is similar to that used in the hardness test ($HV=1.8544F/l^2$) and the units are the same (kg/mm^2).

Hardness test of welded joints

Hardness tests are usually carried out on ground or polished surfaces and sometimes chemically attacked to better define the different areas of the weld. They may be carried out on the surface of the weld, longitudinally and transversally to the weld, or on sections of the weld.

The type of test to be carried out depends mainly on the hardness or strength of the material, the size of the weld and the type of information desired.

The Brinell test produces a large footprint and is therefore applicable for large joints and heavy thicknesses. The Rockwell test produces a much smaller footprint, suitable for measurements close to each other. The Vickers and Knoop test fingerprints are relatively small and suitable for measurements in different regions of a thermally affected area and at close proximity to each other.

2.1.5. Macrographic test

Macrography is the study of properly prepared metal surfaces by observing them under low magnification in order to be able to observe large areas of the specimen surface. This method is used on a wide variety of parts, but especially on castings or those that have undergone a forming process due to severe plastic deformation.

Information provided by the test

Its purpose is to detect possible defects. Observation can be made with the naked eye, with a magnifying glass or with an optical microscope. The macroscopic test is performed by cutting the specimen from the welded area of the material, previously selected, and reveals various types of heterogeneities:

- **Chemical heterogeneities** such as segregations, nitrurations and cementations.

- **Mechanical heterogeneities.** Arising mainly from cold working or any other process that introduces permanent stresses into the metal.
- **Physical and geometrical heterogeneities** such as over-thicknesses, porosities, undercuts, lack of fusion and slag inclusions.
- **Structures.** Heat affected zones, zones of grain size increase, pass numbers, zones of different heat treatments.

2.1.6. Health and Safety

This type of testing is usually carried out in a workshop or in a specialised laboratory. With regard to the health and safety of personnel qualified to carry out the required mechanical tests, this section contains a brief reminder of the possible risks that exist in this type of installation.

- **Physical hazards due to specimen preparation and subsequent test performance:**
    - Noises
    - Vibrations
    - Poor lighting
    - Falls and impacts
    - Cuts
    - Cushing

Chemical hazards due to metallographic preparation of specimens:

- Reagents
- Vapours
- Fumes

2.2. Introduction to Non-Destructive Testing (NDT)

Destructive tests applied in statistical quality control make it possible to check, with a certain degree of certainty, the quality of a production. However, as mentioned above, it is necessary to disable a certain number of samples, providing data on a local area of the product, but not on its entire volume, without being able to ensure the quality of all the elements of a production.

Non-destructive testing (NDT) allows the inspection of 100% of a production run and the inspection of the entire volume of a product. However, it should be noted that NDT does not provide information on the mechanical properties of the inspected material, but it does serve to detect potentially catastrophic imperfections, thus ensuring a certain degree of reliability.

The use of NDT in a production system confers the following advantages:

- They allow 100% inspection of a part or a production run and the collection of data on the entire volume, helping to maintain a uniform level of quality in the product and in production. They are applicable at any stage of the production process.
- Applied in the maintenance and monitoring operations of the systems throughout the service, they contribute to ensure their functional quality and help prevent accidents.
- Adapted to the object to be tested.
- Provide direct and indirect economic benefits:
  - *Direct benefits* in terms of reduced manufacturing costs by eliminating, at the early stages of production, products that would be rejected in the final inspection.
  - *Indirect benefits,* such as improved design and control of manufacturing processes.

The success of the application of non-destructive testing to an industrial problem is conditioned, fundamentally, to the fulfilment of the following requirements:

- That the test allows the basic stages of the inspection to be carried out correctly.
- That, taking into account economic factors, the trial be programmed under the criterion of maximum economic return and benefit.

They also have the following limitations:

- Heavy reliance on the operator. Theoretical and practical education and training of the operator is essential for a positive inspection result.
- There is no formal training. They are not qualifications recognised by the education system.
- They need standard test tubes. And in some cases complex calibrations and verifications.
- There is no absolute method. In many cases it is necessary to perform more than one of the methods on the same part.

2.2.1. Classification of NDT

- **VOLUMETRIC TESTS.** These are tests that allow us to examine up to 100% of the total volume of the object under test.
- **SEMI-VOLUMETRIC OR SUB-SURFACE TESTS.** These are tests that allow us to examine a part of the volume of the object under test.
- **SURFACE TESTS.** Surface tests are those that allow us to examine only the surface of the object under test, and are therefore suitable for detecting discontinuities that emerge at the surface.

Each non-destructive testing method is based on some physical phenomenon that allows us to identify the phenomenon with the imperfection.

- Visual inspection → Visible light.
- Penetrating liquids → Surface tension.
- Magnetic particles → Electromagnetic energy (magnetic field).
- X-rays → Electromagnetic energy (photons).
- Eddy currents → Electromagnetic energy (current).
- Ultrasound → Mechanical energy (elastic waves).
- Acoustic Emission → Mechanical Energy (elastic waves).

This topic will describe some of the most commonly used non-destructive tests in industry. The applications of NDTs are very diverse:

They can be used to characterise samples, both in terms of their nature and their condition. The most common use is the detection of heterogeneities or discontinuities, both in manufacturing (im-perfections or defects) and in service (deterioration or failures). They can also be used in metrology, for the measurement or determination of geometric parameters. In terms of industrial sectors, NDTs are used in all of them, a list is given below as an example:

- Aeronautics
- Art
- Construction
- Metallurgical
- Nuclear
- Etc…
- Alimentation
- Automotive
- Railway
- Naval
- Petrochemical

2.2.2. Advantages and limitations of NDTs

The advantages and limitations of the most commonly used NDT methods are given below.

VISUAL INSPECTION	
ADVANTAGES	**LIMITATIONS**
It is very accessible. Relatively simple. Applicable to any material. Allows precise location of discontinuities.	Only detects surface discontinuities. Requires well-trained operators. Cannot determine the depth of the discontinuity.
PENETRATING LIQUIDS	
ADVANTAGES	**LIMITATIONS**
Fast. Easy to apply. Very sensitive. Very portable. Applicable to any material, except very porous ones.	Only detects surface discontinuities. There is a risk of contamination. It is not possible to determine the depth of the discontinuity.
MAGNETIC PARTICLES	
ADVANTAGES	**LIMITATIONS**
Fast. Easy to apply. Very sensitive. Highly portable. Accurately determines the length of the discontinuity.	Can only be applied to ferromagnetic materials. Only detects surface and sub-surface discontinuities. There is a risk of contamination. There is remanent magnetism. The depth of the discontinuity cannot be determined.

EDDY CURRENTS	
ADVANTAGES	**LIMITATIONS**
High sensitivity. Highly versatile. High portability. No coupling required. High inspection speed.	Only detects surface and sub-surface discontinuities. Only applicable to electrically conductive materials. There is a mixture of many variables. Difficult to apply to ferromagnetic materials.
INDUSTRIAL RADIOGRAPHY	
ADVANTAGES	**LIMITATIONS**
Provide a document. Relatively easy observation. Applicable to any material. Very sensitive to three-dimensional discontinuities. Numerous special techniques.	Requires access from both sides. Not suitable for detecting flat discontinuities. There are risks of irradiation. Difficulty in large thicknesses. High investment in equipment and safety.
ULTRASOUNDS	
ADVANTAGES	**LIMITATIONS**
High penetration power. High sensitivity. Accuracy in determining the position of the reflector. Only requires access from one surface. Instant response. Can be automated. Inspects the entire volume. No risk to people. High portability.	Requires skilled operators. Requires extensive knowledge of testing techniques. Difficult to apply on rough, thin or irregular parts. Difficult to detect discontinuities close to the surface. Requires coupling medium. Requires reference blocks.

Basic stages of non-destructive testing inspection

The basic steps in the inspection of a material, component, weld, etc., by non-destructive testing methods, with regard to problems of defectology, characterisation and metrology, can be summarised in the following four steps:

- Choice of appropriate method and techniques:

The nature of the material, its structural state and product form must be taken into account, as well as the type of heterogeneities that may occur, since all methods have limitations of interpretation, limitations due to the geometry and nature of the material, as well as limitations in the field of observation and in the speed of application allowed by the test.

- Obtaining indications:

In order to obtain a proper indication of a heterogeneity present in the material, it is necessary to have knowledge of the characteristics of the products, of the heterogeneities that may occur and of the types of heterogeneities that can be detected by the different operational techniques that each method allows.

- Interpretation of indications:

Once the indication has been obtained, it is necessary to interpret it, i.e. to correlate the observed indication with the nature, morphology, location, orientation and size of the discontinuity that generated the indication.

- Assessment of indications:

Once obtained, interpreted, measured and quantified, the indication should be evaluated, i.e. compared with an acceptance criterion. It is not the inspector's job to decide whether a weld is good or not. Nor is it the role of the inspector to choose the test method or the required quality level.

2.3. Test principles and applicability

Visual inspection (**VT**) is the most widely used non-destructive test. The main reasons for its use are its simplicity, ease of use, speed of execution and the economy of its application. However, despite its simplicity, it should never be forgotten. Even when more sophisticated tests are planned, a visual inspection should always be carried out as a preliminary step. This will facilitate the subsequent work and, in many cases, will be the decisive element for continuing the established production sequence with a real chance of success.

Visual inspection is not decisive for classifying a weld as acceptable as this test is **limited to the surface only**. To study the subsurface or the interior of the material, other tests such as radiography, ultrasound, magnetic particles, etc. must be applied.

Focusing on the inspection of welds, the inspection begins when the material arrives at the welding depot, continues throughout the welding process and ends when the inspector examines the finished equipment, marks the areas to be repaired and completes his inspection report. Conscientiously applied by experienced personnel, visual weld inspection:

- Identifies non-compliant materials.
- Facilitates the correction of defects during the manufacturing process to avoid rejection after rejection.
- Reduces the need for further NDT.

2.3.1. Conditions for carrying out the test

Perhaps because visual inspection is so routine, it was not until the 12th century that a Franciscan friar, Roger Bacon, laid the foundations for proper visual inspection. Here are the nine conditions Roger Bacon lists in his *Opus Maius* for observing correctly:

1. Convenient light.
2. Safe distance.
3. Adequate position (of the observer).
4. Appreciable size of the object under examination.
5. Different density (i.e. contrast with respect to a background).
6. Transparency of the medium (between the object and the eye).
7. Sufficient time.
8. Sound eyesight.
9. Suitable position of the object under examination (access to the surface to be examined).

2.3.2. Qualification of personnel: ISO 9712

It is worth mentioning here what is required of the inspector in terms of visual acuity.

Table 1

Section 7.4 Visual acuity - all levels. UNE-EN ISO 9712
The candidate must provide evidence of satisfactory vision in accordance with the following requirements:
Near vision should be able to read at least Jaeger Standard Letter Scale 1 or 4.5 Times Roman size or equivalent (with a height of 1.6 mm) at a distance of not less than 30 cm, with one or both eyes, with or without correction.
Colour vision must be sufficient for the candidate to distinguish and differentiate the contrast between the colours or greyscales used in the NDT method to be used, as specified by the employer.
The certification body may consider replacing the requirements specified in a) in accordance with an appropriate alternative.
After certification, near vision acuity checks must be performed annually and verified by the employer.
Absence of colour blindness
Certificates issued by opticians, indicating their membership number, as well as certificates issued by mutual insurance companies without a membership number, shall be considered valid.

To be a visual inspector, it is not enough just to see well. In fact, inspectors with adequate knowledge and extensive experience can perform more effective inspections than an inspector with perfect vision who lacks knowledge and experience.

It should not be forgotten that the first inspector of the welded joint is always the welder who, although not certified to carry out inspections, has great experience in the welding process and the material he works with on a daily basis.

Irrespective of the codes or standards that apply to the certification of non-destructive testing personnel, such as visual inspection, the visual inspector must have a good command of codes, standards, specifications, drawings, symbology and welding design. He/she should have sufficient knowledge of how materials should be prepared for welding, how equipment and operators should operate during welding and how the finished weld should look.

2.3.3. Detectable defectology

Defectology before welding

Visual inspection includes the inspection of the parts before welding. In this inspection various assembly defects can be found such as:

- Misalignments between parts.
- Angular deformations.
- Faulty settings, etc.

It should be taken into consideration that it is usual to assemble the parts by slightly modifying the dimensions established in the drawings, in order to compensate for the effect of the deformations produced during welding.

Defectology after welding

By visual inspection, different types of defects can be detected, sometimes even intuiting the presence of some, located below the surface.

- **Lack of Fusion**. They are detected by the appearance of depressions between the bead and the base metal. They can also be seen by a certain overlapping of the edges of the bead on the base metal, which indicates that the bath has overflowed onto the solid material. **Lack of fusion is not always detectable by this method**.
- **Lack of Penetration**. It causes a certain depression along the side opposite to the part to be welded, by examining the root this anomaly can be detected, if possible.
- **Undercuts.** They are easily identifiable, indicated as depressions in the base material along one of the two sides of the seam.
- **Lack of Filler Metal.** They are easily identifiable and appear where the welder has not completely filled the joint to be welded.
- **Slags, Oxides and Scale**. They are only detectable if they are superficial. Their detection and removal means increased corrosion resistance of the weld.
- **Cracks.** Cracks come in several forms:
  - Hot cracks develop along the central axis of the weld.
  - Cracks in the heat-affected zone occur along the edge of the weld seam, these cracks are usually very fine and Inspectors may need to use magnifying glasses to detect them.
  - Crater cracks appear at the ends of the cords and are usually star-shaped.
- **Arc Barley.** They originate when the arc is established outside the edges of the joint to be welded, and may contain tiny cracks.
- **Splashes or Spatters.** These are small metal droplets that are ejected from the joint to be welded and produce hot spots on the base metal, but their size is usually so small that they do not cause

any serious problems. Where appearance is a deciding factor, they should be eliminated, even if their effects are considered to have little detrimental effect.

- **Dimensional Deviations.** They are easily detectable and can be assessed by means of easy-to-use instruments. They can be dimensional deviations from the dimensions of the workpiece and dimensional deviations of the weld seam.
- **Deformations.** By observing the finished assembly, it is possible to detect whether deformations have occurred. By studying the surface of the weld, it is possible to know if the work was carried out correctly, since when the weld is welded at a suitable speed and with suitable parameters, the weld has a regular contour with uniform water and penetration. Such as excessive over-thickness, asymmetry, etc.

Visual inspection of welds can be carried out in two ways:

- **Direct visual inspection**. The inspector carries out his work without the use of image processing devices. This can be done without aids or with auxiliary elements such as lenses, gauges, etc.
- **Indirect or remote visual inspection.** The inspector makes use of available mechanical and/or optical equipment that complements the eyes, and allows them to perform a more thorough inspection.

2.3.4. Optical aids for direct visual inspection

Geometrical optics is the discipline that explains the manipulation of light by means of mechanical accessories that produce an image for human observation. These mechanical accessories can be classified as mirrors, lenses and prisms. Prisms currently have no common application in visual inspection, therefore the physical basis of their interaction with light will not be developed in this topic.

It is common for the visual inspector to need the following tools to carry out his or her work:

- **Mirrors**

Mirrors change the direction of light by reflection. Mirrors can be flat, convex, concave or parabolic.

They are typically used when access to the area to be inspected is difficult, for example, when inspecting the root of a butt weld. They are available in different sizes and can be incorporated into an extendable element to facilitate the inspector's access.

Figure 1 - Flat mirror for weld inspection.

- **Lenses**

Lenses are transparent objects (usually made of glass), bounded by two surfaces, at least one of which is curved.

The most common lenses are based on the different degree of refraction that the rays experience when striking different points of the lens.

Figure 2 - Manual and fixed magnifier

The loupe is the most commonly used tool to magnify the image observed by the inspector. They consist of a converging lens. It can be manual or fixed. There are also comparators which are magnifying glasses with measuring capabilities. Some have interchangeable scales which allow them to measure diameters, radii, angles, distances, etc.

There are also pocket microscopes which are tubes with a small diameter (about 12 mm) and a length of about 15 cm, although larger diameters are also available. Some varieties reach X150 magnification. An auxiliary light may be incorporated to facilitate inspection. See Figure 2.

Lighting devices

Sometimes it is necessary to have an "extra light" to be able to carry out the visual inspection, for example to inspect the root of a weld on a pipe where ambient light does not reach. It is common for the inspector to carry a small torch to assist him in his task. The torch is used to illuminate those areas where ambient light is not sufficient and to create shadows that can be indicative of the existence of undercuts, surface porosity, shrinkage, etc.

Figure 3 shows a diagram of how the use of a torch can help locate an undercut.

Figure 3 - Localisation of undercut by projecting its shadow

Dimensional measurement

For the characterisation of an indication to be complete, it is necessary to know its dimensions. An acceptance criterion can give an indication as acceptable or unacceptable depending on its dimensions. In visual inspection of welds, it is common to have to take measurements of the depth and length of undercuts, angles of agreement, overthicknesses, excess penetration, angular deformation, misalignment of butt-jointed parts, length and thickness of slag inclusions, etc. For this purpose, devices such as a simple flexometer or more sophisticated tools such as those described below are used.

- **Simple welding gauge**

It measures fillet welds between 3 and 15 mm thick. The gauge shall be positioned with the curved part of the fusion faces so that it has three points of contact with the workpiece and fillet welds. It can also measure the overthickness of butt welds with the straight side.

Figure 4 - Simple welding gauge

Because these gauges are made of relatively soft aluminium, they wear out quickly.

- **Set of welding gauges**

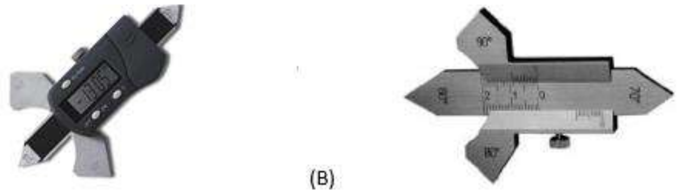
It measures fillet welds between 3 and 12 mm thickness, from 3 to 7 mm the graduation is 0,5 mm, above that only 8 mm, 10 mm and 12 mm are available. The gauge measures using the three-point contact principle.

Figure 5 - Set of welding gauges

- **Welding gauge with calibration**

Measures fillet welds, can also determine overthickness of butt welds.

The sides of the gauge are shaped so that face-to-face angles of 60˚, 70˚, 80˚ and 90˚ can be measured in V- and single V-butt welds.



(A) (B)

Figure 6 - Welding gauge with digital calibration (A) and (B) with analogue calibration

- **Internally manufactured welding gauge**

Measures by comparison various throat thicknesses in fillet welds with a 90˚ angle between faces.

Sometimes a manufacturer produces its own templates against which it compares.

Figure 7 - Internally manufactured welding gauge

- **Three scale welding gauge**

Measures throat thicknesses and side lengths. Can also measure butt weld over-thickness. Easy to use. Also suitable for asymmetrical fillet welds.

Figure 8 - Three scale welding gauge

- **Gauge for checking the profile of fillet welds**

Verifies the profile of a shape for a fillet weld dimension. This type of gauge requires a model for each fillet weld dimension.

Figure 9 - Gauge for checking fillet weld profile

- **Multipurpose gauge**

Measures bevel angles, fillet weld side lengths, undercuts, misalignments, throat thicknesses and weld overthicknesses.

This gauge is probably the tool most commonly used by the visual weld inspector. However, this tool has the disadvantage of precision: it cannot measure sizes smaller than one millimetre.

- **Universal welding gauge**

On fillet welds it measures shape and dimension. On butt welds it measures plate misalignment, bevel angles, plate spacing, overthickness, length and depth of undercuts, etc.

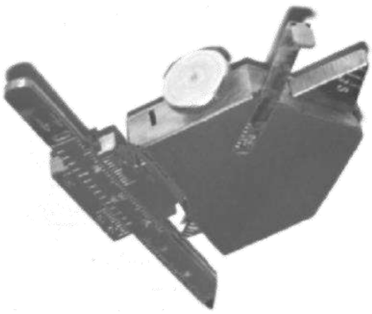


Figure 10 - Universal welding gauge

- **Opening gauge**

Measure the width of the openings. See figure 11.

Figure 11 - Opening gauge

- **Misalignment hook gauge**

Measures the misalignment of the preparation in butt joints of sheet metal and tubes.

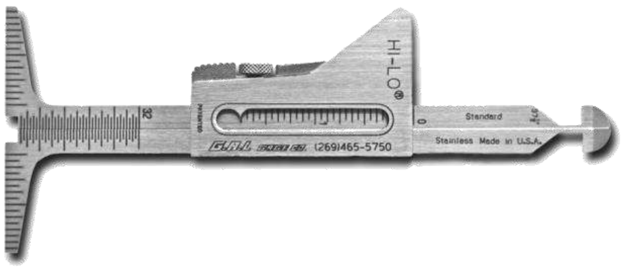


Figure 12 - Misalignment hook gauge

- **Universal butt welding gauge**

Measures preparation and finishing of butt welds:

1. Bevel angle.
2. Width of root opening.
3. Weld overthickness.
4. Width of weld surface.
5. Depth of undercuts.
6. Consumable diameters.

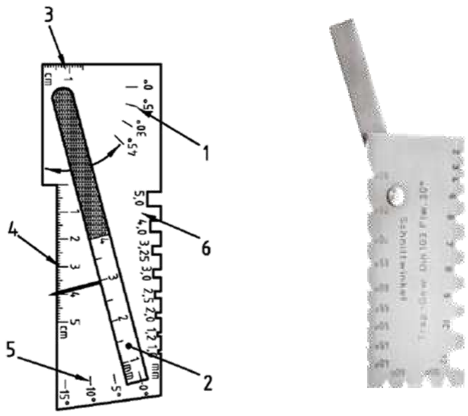


Figure 13 - Universal butt welding gauge

- **Other measuring elements**

In addition to the gauges mentioned above, an inspector has other gauges such as the one shown in figure 14. A very common mistake is to try to measure the throat directly with this gauge. With this tool it is only possible to measure the foot of a fillet weld, the excess of concavity or convexity and, at most, the excess thickness of a butt weld.

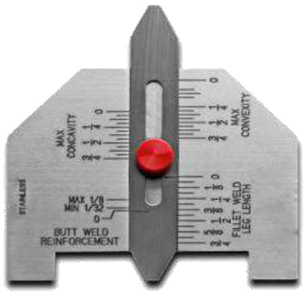


Figure 14 - Fillet welding gauge

For measuring, for example, diameters and thicknesses of plates and tubes, the inspector can also use micrometers, calipers and other measuring devices.

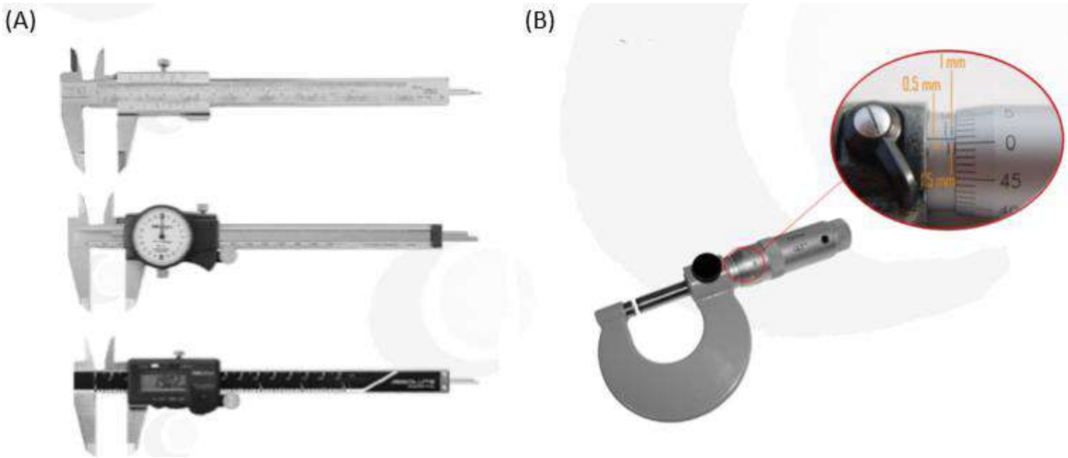


Figure 15 - (A) Caliper and (B) micrometer

2.3.5. Performance of visual inspection in accordance with ISO 17637

Visual inspection involves actions from receipt of material and checking of conditions to inspection of the part in service. ISO 17637 is a very useful tool to determine what aspects should be considered when performing visual inspection before, during and after welding.

ISO 17637. Non-destructive examination of fusion welds. Visual examination establishes the requirements necessary to carry out the visual inspection of welds correctly. It includes recommendations for direct observation, or optimum light intensities (500 lx), etc. It also includes the visual characteristics of the visual inspector and recommendations for equipment such as gauges, callipers, etc.

2.3.6. Visual inspection before welding

When visual inspection is required prior to welding, the joint should be examined to verify that:

- The base material and product type corresponds to that specified in the fabrication drawing and the welding procedure specification (pWPS or WPS).
- The shape and dimensions of the edge preparation meet the requirements of the welding procedure specification.
- Fusion faces and adjacent surfaces are clean of rust and paint, and any surface treatment has been carried out in accordance with the application standard or product standard.

Figure 16 - Cracked spot weld detected during visual pre-weld inspection

- The parts to be joined by welding have been correctly fastened together according to the drawings or manufacturing instructions.
- The welding points which hold the assembly and which are to be remelted during the final welding, are free of defects such as cracks, porosity, inclusions, etc.

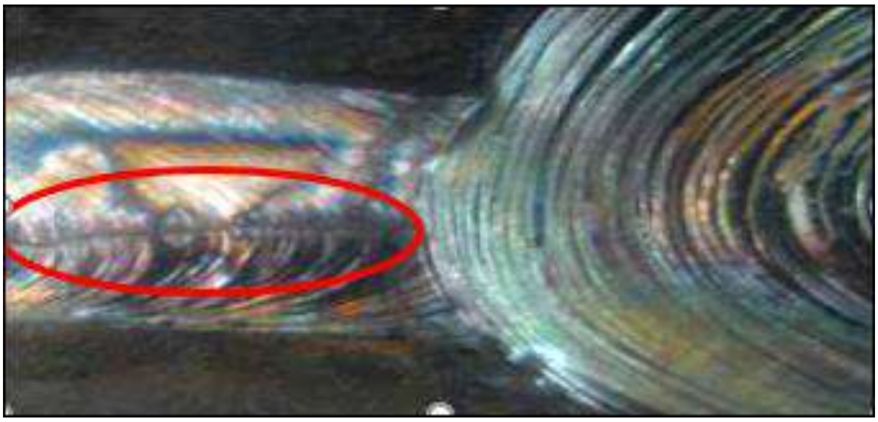


Figure 17 - Crack detected in the root pass partially covered by the filling pass

2.3.7. Test registration

According to ISO 17637, a visual inspection report must contain the following points:

a) Name of the component manufacturer.	h) Acceptance criteria.
b) Name of the inspection team, if different from a)	i) Imperfections exceeding the acceptance criteria and their location.
c) Identification of the object under examination.	j) Scope of the examination with reference to drawings as appropriate.
d) Material.	k) Inspection devices used.
e) Type of joint.	l) Inspection results against acceptance criteria.
f) Material thickness.	m) Name of inspector and date of examination.
g) Welding process.	

2.4. Liquid Penetrant Testing (PT)

The liquid penetrant testing allows the detection of superficial imperfections through the capillarity penetration of a low superficial tension liquid and a great wettability power.

It is a fast and simple process, easy to apply even in irregular components and it is used in all materials (ferrous materials and non-ferrous materials), however this does not include porous materials. Due to the capillarity, even very fine imperfections, such as cracks end lack of fusion are filled with penetrant, which is applied to the cleaned surface to be tested.

The main drawback is that it only allows the identification of imperfection (cracks and porosities) in contact with the outer surface e it is necessary to have access from all sides of the component to be inspected.

ISO 3452-1 is the standard that the specifies a method of the penetrant testing for application, usually for but not restricted, to metallic materials and defines requirements for process and control testing. Some important variables defined by this standard are listed below:

- Penetrant duration: 5 – 60min
- Development duration: 10 – 30 min
- Temperature: 10 – 50ºC

This standard is not intended to be used for acceptance criteria.

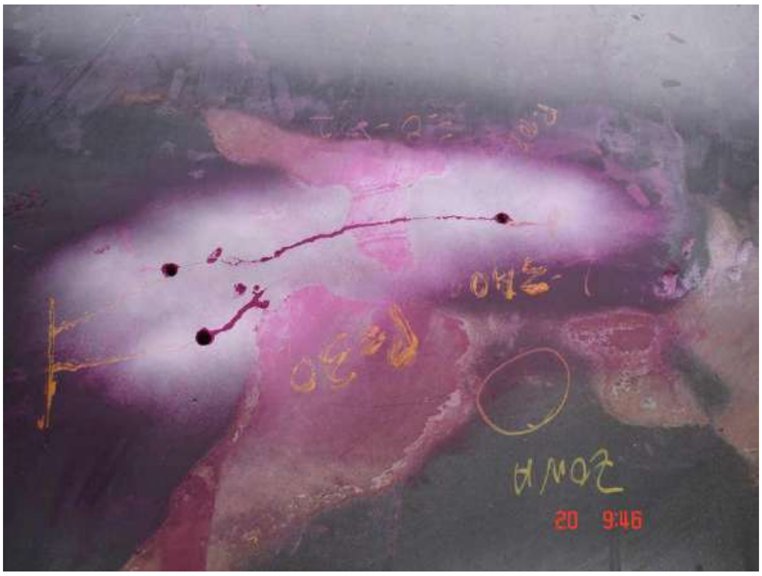


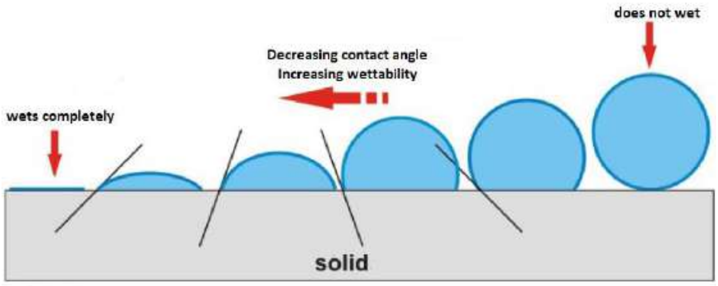
Figure 1 - Illustrative image of a imperfections revealed after liquid penetrant testing

2.4.1. Liquid penetrant characteristics

The basics of the Liquid penetrant testing are based on the following characteristics of a liquid:

- Capillarity or capillary action is defined as the tendency for a liquid to penetrate or migrate into small openings, such as cracks, pits, or fissures. Capillary action is associated with wetting ability. For example, when a tube with a small inside diameter is inserted into a liquid, the liquid level inside the tubing may rise above, remain even, or be lower than the outside liquid level. If the contact angle between the liquid and the tubing wall is less than 90-degrees (the liquid wets the tube wall), the liquid will be higher in the tube than on the outside. When the contact angle is 90-degrees or greater (poor wetting and high surface tension), the liquid will not rise above the outside level and may even be depressed. Capillary rise occurs when a liquid wets the inside of a tube and the surface tension draws additional liquid into the wetted area.

- Viscosity is a measure of a liquid's resistance to a change in physical shape and is related to internal friction. The viscosity of a liquid decreases as the temperature is raised and viscosity increases as the temperature is lowered. Viscosity has no effect on penetrating ability. Some highly viscous fluids, such as molasses, have very good penetrating ability, while some low viscosity liquids, such as pure water, have very poor penetrating ability. However, from an application viewpoint, viscosity affects the speed with which a penetrant enters a discontinuity. Viscosity also determines how much penetrant will remain on a part surface during the dwell period. High viscosity penetrants cling to the surface, requiring increased effort for removal. Very thin penetrants (low viscosity) may drain from the part surface so quickly insufficient penetrant remains to enter discontinuities. Some standards set the minimum viscosity to 5 centistokes. wettability, and colouring.
- wettability is evaluated by the contact angle between the liquid and the contact surface. This angle is measured by the tangent of the contact between the liquid surface and the solid. Poor wettability of the surface is related to a large contact angle while good wettability are related to small contact angles. In liquid penetrant testing the liquid used should have a good wettability in order to be able to work correctly for this goal.



Other important characteristics are:

- Flash point is the lowest temperature at which vapors of a substance ignite in air when exposed to a flame. The flash point does not affect the performance of a penetrant. High flash points are desirable to reduce the hazard of fire. In some specifications the flash point has been defined to be at least 55ºC.
- volatility, the vapor pressure or boiling point of a liquid characterizes its volatility. It is associated with the evaporation rate of liquids and is desirable for penetrant materials to have a low volatility, i.e., a high boiling point. However, in the case of petroleum products, viscosity increases as the boiling point goes up. In this group of materials, the lower viscosity is preferred because they require less penetrating time. Still, for practical purposes, high volatility should be avoided before viscosity becomes a problem. High volatility results in a loss of penetrant in open tanks and can result in penetrant drying on a part during the penetrant dwell, leaving a film difficult to remove.
- Thermal stable is important because the coloring pigments can be affected by the temperature. The dyes used in fluorescent-dye penetrants lose their brightness or color when subjected to elevated temperature. Loss of brightness or color also occurs at moderate temperatures, but at a slower rate. The liquid should not chemically react with the parts to be tested, for example, austenitic steels are attacked by remnants of sulphur in liquid penetrants.
- The liquid penetrant should be easily removed from the surface while remaining inside the discontinuity.
- Toxicity – if the liquid penetrant is not innocuous it can have a toxic effect on the operator. Gloves should be used to avoid allergic reactions.

The penetrant sensitivity refers to the penetrant aptitude to reveal small and narrow discontinuities, like sharp cracks. The sensitivity is the capacity of penetration and coloring of the penetrant. The cracks can present a reduced volume, so the penetrant should be able to enter the discontinuity, fill it entire volume, exit the discontinuity revealing the existence of a defect.

There are four levels of sensitivity, with level 1 being the lowest and is used to reveal only large discontinuities while level 4 has a very high sensitivity and can reveal really small discontinuities. Sensitivity levels shall be determined according to ISO 3452-2.

2.4.2. Different groups of liquid penetrant particles and methods

The liquid penetrant testing can be divided in two methods, penetration method and transparency method.

The former uses a visible penetrant liquid, usually red, that produces a contrast with the developer, usually white. The latter uses a fluorescent penetrant medium that is visible when exposed to a black light. The sensitivity of the latter method is better, but both methods provide good results when correctly applied.

The materials necessary for the execution of the method are penetrant liquids, cleaning liquids for the penetrant excess (water, water after emulsification and special solvents) and developers (in powder or in suspension in a liquid with a small granulometry).

The different type of penetrant liquids that exist are natural or fluorescents removable by water, emulsified water or adequate solvents. The liquid can be applied using a brush, spray or submerged in trays.

2.4.3. Penetrant family

The table below details designation established by ISO 3452-1 standard for the liquid penetrant families

Penetrant		Excess Penetrant remover		Developer	
Type	Denomination	Method	Denomination	Form	Denomination
I	Fluorescent	A	Water	a	Dry
II	Colour contrast	B	Lipophilic emulsifier	b	Water-soluble
III	Dual purpose (fluorescent and colour contrast	C	Solvent	c	Water suspendable
		D	Hydrophilic emulsifier	d	Solvent-based (non-aqueous for type I)
		E	Water and solvent	e	Solvent-based (non-aqueous for type II and III)
				f	Special application
				g	No developer (type 1 only)

A product family is understood as the combination of the following penetrant testing materials: penetrant, excess penetrant remover except for method A and developer. A product family may be defined by the manufacturer, user or inspection authority and the testing materials do not necessarily have to be from the same manufacturer but should be type tested with the respective standard.

The product family to be used for penetrant testing is given a designation comprising the type, the method and the form for the testing products, and a figure which indicates the sensitivity level.

A product family comprising a fluorescent penetrant (I), water as the excess penetrant remover (A), and a dry-powder developer (a), and having a system sensitivity of level 2 gives the following penetrant testing system designation when using ISO 3452-1 and ISO 3452-2: product family ISO 3452-2, IAa Level 2.

The penetrant can be fluorescent, color contrast or both. The color penetrant liquid, usually red, produces a contrast with the developer, usually white. The fluorescent penetrant is visible when exposed to black light. The sensitivity of the fluorescent liquid is usually better but both methods provide good results.

The excess penetrant removers should be able to remove the excess penetrant from the surface of the component without removing the penetrant inside the discontinuities. These removers can be:

- Water - water is used for removal it shall be applied by wiping, immersion or spray;
- Solvent - Excess penetrant shall be removed first by using a suitable clean lint-free cloth or absorbent paper and subsequently by using a clean lint-free cloth lightly moistened with solvent;
- lipophilic emulsifier – To allow the post-emulsifiable penetrant to be removed from the test surface, it shall be rendered water-rinsable by application of an emulsifier. This can only be done by immersion;

- hydrophilic emulsifier – To allow the post-emulsifiable penetrant to be removed from the test surface, it shall be rendered water-rinsable by application of an emulsifier
- water and solvent - the excess water-washable penetrant shall be removed using water. Subsequently the surface shall be wiped with a clean lint-free cloth, lightly moistened with solvent.

The basic function of all developers is to improve the visibility of the entrapped penetrant indication. The improvement in visibility is achieved through a number of mechanisms including the following:

- Assistance in extracting the entrapped penetrant from discontinuities.
- Spreading or dispersing the extracted penetrant laterally on the surface, thus increasing the apparent size of the indication.
- Improving the contrast between the indication and the background.

The developers can be:

- Dry developer may only be used with fluorescent penetrants and a thin layer should be uniformly applied to the test surface. Techniques like dust storm, electrostatic spraying, flock gun, fluidized bed or storm cabinet can be used for this goal. Local agglomerations should be avoided;
- Water soluble developer where a uniform application of the developer should be carried out by immersion or by spraying with suitable equipment. The part should be dried by evaporation and/or by a drying oven;
- Water-suspendable developer where a thin, uniform application of the developer shall be carried out by immersion in agitated suspension or by spraying with suitable equipment in accordance with the approved procedure. The part should be dried by evaporation and/or using a forced-air circulation.
- Solvent-soluble developer should be applied by spraying uniformly. The spray should guarantee that the developer is slightly wet when contacting the surface, giving a thin, uniform layer.
- Developer for special application the surface should be cleaned with clean and dry cloth, applying the penetrant, removing the excess penetrant and apply the peelable developer as recommended by the manufacturer.
- No developer should be only used for type I penetrant.

2.4.4. Test Procedure for liquid penetrant testing

First step – Washing and cleaning of the component surface using a very low surface tension liquid with solvent, detergent, or vapor. Mechanical cleaning should be avoided or eliminated.

Second step – Drying is the final stage of the precleaning.

Third step – Application of penetrant liquid with a high superficial tension and great wettability during to 5 to 60 minutes at a temperature from 10 to 50ºC.

Fourth step – Removal of the penetrant liquid in excess using a high surface tension liquid and adequate to the penetrant type. The removal in some cases can be made using water, water after emulsification or a special solvent.

Fifth step – Drying of the surface

Sixth step – Application of a developer in powder or in suspension of a liquid with a small granulometry and applied in a small and homogeneous layer.

Seventh step – Drying of the surface only when the developer is an aqueous liquid.

Eight Step – Observation and record of the results. The observation must be made after the application of the developer, but the results can only be recorded after 10 to 30min, after development. A black light should be used with fluorescent penetrant liquids (a black ultraviolet light with a wavelength of 360nm)

Nineth step – Final surface cleaning to eliminate a possible corrosion action due to the existence of sulfur or halides (fluorine, chlorides, bromides and iodides).

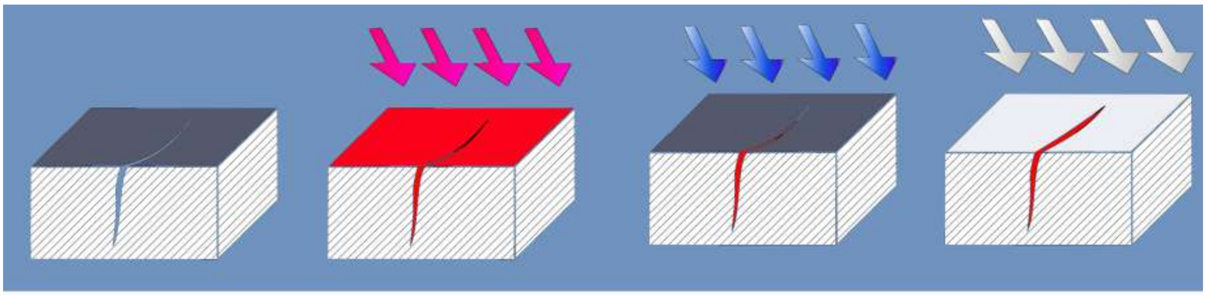


Figure 2 - Representation of the steps performed on the liquid penetrant testing

2.4.5. Liquid penetrant testing features

This process can identify following types of defects:

- Only imperfections which are open to the test surface;
- Cracks;
- Pores;
- Lack of fusion;
- Overlap.

Cracks width with sizes up to 0,5μm can be displayed.

The working equipment needed to perform these tests are the:

- Penetrant;
- Developers;
- Water or solvent as an intermediate cleaner;
- Possibly UV lamp, depending on the nature of the penetrant.

The following prerequisites are needed:

- One-sided accessibility;
- The surface should be clean, dry and grease-free;
- Low contour surfaces should used for maximum test sensitivities;
- Temperature should be between 10 to 50ºC;
- The material to be tested should not be too porous;
- The material should no be destroyed by test chemicals.

2.4.6. Evaluation and test reporting

ISO 23277 specifies the acceptance levels for indications from surface breaking in metallic weld detected by penetrant testing. These acceptance levels are intended to be used in the manufacture inspection but where appropriate it can also be used for in-service inspection.

This standard defines different levels of acceptance by imposing limits to the maximum length of linear indications, e.g. cracks, lacks of fusion, or maximum dimension of non-linear indications, e.g. pores, inclusions,

When performing the liquid penetrant testing the documentation associated with the test should include sketches, photographs, and test report with the minimum content according to ISO 3452-1.

The minimum content of the test report should be:

- Information of the tested component;
    - Designation
    - Dimensions

    - Material
    - Surface condition;
    - Production stage.
- Test goal
- Designation of the liquid penetrant system, as specified in ISO 3452-1 standard, providing the name of the manufacturer, the product's designation as well as heat number
- Test instructions
- Deviations, if they exist, from the testing instructions;
- Test results, providing a description of the identified cracks;
- Testing location, testing date and operator name;
- Name, qualification and signature of the test supervisor.

2.5. Magnetic Particle Testing (MT)

The magnetic particle testing allows the detection of superficial or sub-superficial imperfections through the application of a strong magnetic field on the component.

This process is usually applied to magnetizable materials, and the detection sensitivity is usually larger than the liquid penetrant testing. It is a very practical way of testing fillet welds in steel construction. Manual yokes are often used for this application.

The conductivity for magnetic fields (permeability) is very high in steels which are commonly used for machine, steel plant construction. Any imperfection, such as lack of fusion or cracks, create significant resistance to a magnetic field. At such imperfection, the magnetic field escapes at the surface of the test piece (leakage flux). Extremely fine magnetic particles, which are mixed to a paste in water and oil, show the location of the leakage flux and/or cracks or lack of fusion.

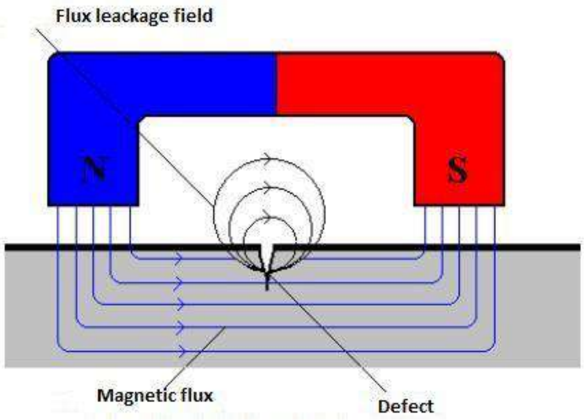


Figure 1 - Illustrative image of the leakage flux that occurs above the defect (source: TUV Nord)

The magnetic particle also shows imperfections which are close to the surface (maximum 3mm). For optimum detection sensitivity, the surface should be bare metal. Coatings such as varnishes reduce the test sensitivity from layer thicknesses of 50µm. With colored test, black magnetic flux is often used. A white base color, which is sprayed onto the test piece prior to the test, creates a good contrast.

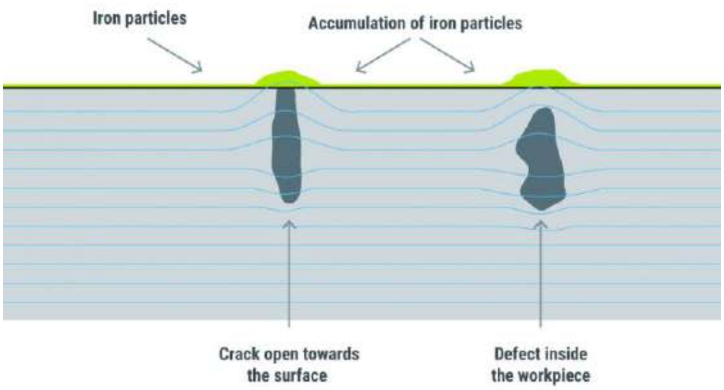


Figure 2

Fluorescent test equipment generates a particular high-test sensitivity on smooth, bare metal surfaces. For evaluation, a UV lamp and daylight shielding are, however, necessary.

ISO 17638 is the standard that the specifies techniques for detection of surface imperfections in welds in ferromagnetic materials, including the heat affected zones, by means of magnetic particle testing. The techniques are suitable for most welding processes and joint configurations. This standard does not provide any acceptance criteria.

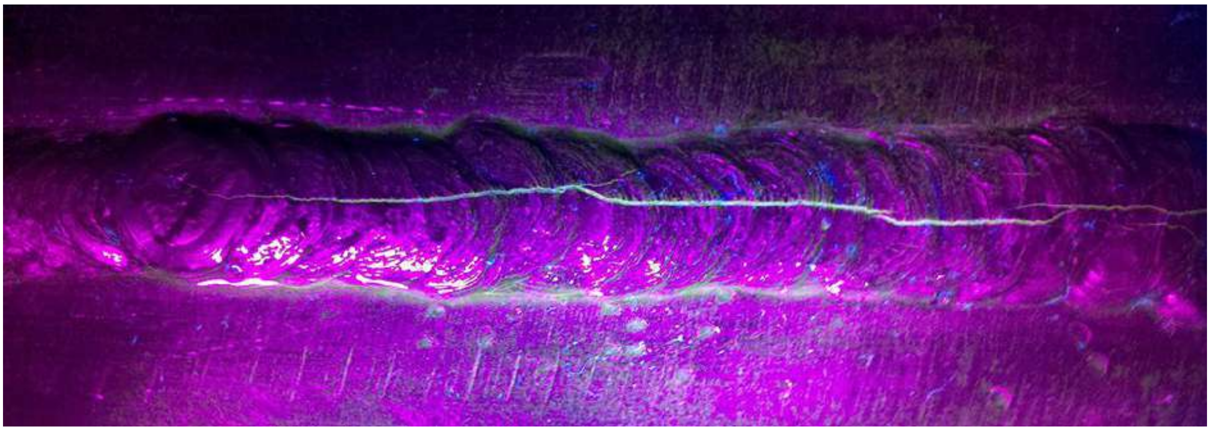


Figure 3 - Illustrative image of an imperfections revealed in magnetic particle testing (Source: UTM Shipping service)

2.5.1. Magnetization types

The magnetic particle NDT method can be divided in two groups:

- the method of direct current or alternate current passage through the component (direct magnetization);
- the induction method (indirect magnetization), where the part whose material properties are to be tested is led through a test coil with an exciter coil and a measuring coil. An impressed alternating current is applied to the exciter coil, and the resulting magnetic alternating field induces eddy currents in the testing material.

2.5.1.1. Yoke magnetization

Yoke magnetization is the most common for testing welded joints. The two poles of an electromagnet are mounted in such a way that a test piece closes the magnetic circuit. Imperfection which lie across the magnetic field are particularly well indicated. Imperfections which lie in the same direction as the magnetic field may not be indicated.

Figure 4 - Magnetization with the manual yoke magnet

2.5.1.2. Magnetization via current-carrying conductors

The magnetic field that surrounds the current carrying conductor (auxiliary conductor) in a ring shape magnetizes the test piece. Imperfections which lie across the magnetic field are particularly well indicated. Imperfections which lie in the same direction as the magnetic field may not be indicated.

Magnetization in two different directions allows all defects to be detected, regardless of their orientation,

Figure 5 - Magnetization via current-carrying conductors

2.5.1.3. Axial current flow

Figure 6 - Magnetization via current flow

In the case of axial current flow, an electrical current pass through the test piece. During current flowing it is important to ensure that stray arcs do not occur as a result of poor contact. The magnetic field strength is proportional to the current intensity. In order to generate a strong magnetic field and therefore a good indication, correspondingly high currents up to several thousands amperes are used. In contrast, the voltage of the testing devices is low (often under 10V), so that the tester is not at risk of electric shock. Only axial orientated imperfections will be detected with this magnetization test.

2.5.1.4. Coil magnetization

During coil magnetization, the test piece can be placed on a layer of insulation in the coil. The coil can also be routed beyond the test piece (overflow coil).

Figure 7 - Magnetization via coils

2.5.2. Particles and application methods

There are several magnetic particles, with different colors, mobility, and fluorescence. The correct choice of this type of particle should allow the best contrast in the part in analysis. The application methods are:

- Dry medium – colored or fluorescent "powder" particles;
- Wet medium – black or fluorescent particles in suspension in a water or petrol-based liquid;
- Continuous method – applicable during magnetization;
- Residual method – applicable in residual magnetization.

The particle application methods can be:

- Spraying with or without equipment;
- In suspension in a bulk liquid;
- In suspension in a liquid for spray.

For superficial imperfections it is necessary the use of alternate current (AC) and for sub-superficial imperfection it is necessary the use of direct current (DC) and it is necessary a field indicator to observed the existing flux.

This method reveals imperfections of the magnetic flux that can be associated to the presence of defects, but also to the shape changes or magnetic permeability. Taking this into account it is necessary to know the part to be controlled to correctly interpret the defects. If the part has a heat treatment, just welded, has a zinc coating, among others, since these features can considerably influence the magnetic permeability of the material it may.

2.5.3. Test Procedure for magnetic particle testing

First step – Washing and cleaning of the component surface using mechanical or chemical cleaning.

Second step – Application of the correct magnetization

- For Direct magnetization with non-movable tips or indirect with a main conductor apply 28 to 36A/mm for test piece diameter and diagonal (D) smaller than 125mm, apple 20 to 28 A/mm for D between 125 to 250mm and apply 12 to 20 A/mm for D between 250 to 400mm
- For Direct Magnetization with movable tips apply for each 25mm of distance between tips, for components thicknesses smaller than 19mm. Apply 90 to 110A and in thicknesses over or similar to 19mm. Apply 100 to 125A for a 200mm maximum distance between tips.
- For Indirect Magnetization by ring (solenoid). For components with a length (L) to diameter (D) ratio (L/D) lower than 15 and equal or larger than 4 apply the formula NI = 35000/(2+(L/D)) and for a L/D equal or larger than 2 and smaller than 4 apply the formula NI = 45000/(L/D) for a L_{max} of 450mm.
- For an Indirect Magnetization with a "Yoke" for a maximum distance between poles the attractive force has to be larger than 4,5kg in AC and , in DC and permanent magnet the force should larger than 18,5kg (for thicknesses larger than 6,4mm).

Third step – Application of magnetic particles:

- Continuous method, using a dry process, for rough surface (for temperatures up to 316ºC)
- Continuous method, using a humid process, for smooth and low roughness (for temperatures up to 57ºC)
- Residual (only applicable in high retention components and after acceptance by the client)

Fourth step – Observation of results which is immediate with a black light with a wavelength of 360nm for fluorescent particles.

Fifth step – Demagnetization when necessary, in tunnel using the equipment with a ring coil, after longitudinal magnetization, in the East-West direction, above the "Curie" point.

Sixth step – Final surface cleaning to eliminate a possible corrosion action due to the existence of sulfur.

Figure 8 -Representation of the steps performed on the liquid penetrant testing

2.5.4. Magnetic particle testing features

This process can identify following types of defects:

- Cracks (max. 0,3mm beneath the surface);
- Lack of fusion;
- Overlap.

The working equipment needed to perform these tests are the:

- Contrasting color;
- Magnetic flux suspension;
- Magnetization device;
- Possibly UV lamp, depending on the nature of the penetrant.

The tests results are documented in a test report, which includes the content required by the respective standard as a minimum. The indications can be captured, for instance, by means of photographs or sketches.

The following prerequisites are needed:

- Surface drying;
- Surface free from dirt, scales, rust;
- Grease-free surface;
- It must be possible to generate a magnetic flow in the test piece (accessibility);
- Coatings should not exceed 50µm.

It should be highlighted that abrupt weld transitions (fillet welds) can form indications, in these case a soft transition between weld and parent material must be created by grinding.

2.5.5. Evaluation and test reporting

ISO 23278 specifies the acceptance levels for indications of imperfection in ferromagnetic steel welds, detected by the magnetic particle testing. These acceptance levels are intended to be used during manufacturing inspection.

This standard defines different levels of acceptance by imposing limits to the maximum length of linear indications, e.g. cracks, lacks of fusion, or maximum dimension of non-linear indications, e.g. pores, inclusions. To ensure detection of imperfections in all orientations, the welds shall be magnetized in two directions approximately perpendicular to each other with a maximum deviation of 30°.

When performing the magnetic particle testing the documentation associated with the test should include sketches, photographs and test report with the minimum content according to ISO 17638.

The minimum content of the test report should be:

- Name of the company carrying out the test;
- The tested object
- Testing date;
- Parent and weld materials;
- Indication if any post weld heat treatment was made
- Type of joint;
- Material thickness;
- Welding process(es);
- Temperature of the test object and the detection media (when using media in circulation) throughout testing duration;
- Identity of the test procedure and description of the parameters used, including the following:
    - Type of magnetization;
    - Type of current;
    - Detection media;
    - Viewing condition.
- Details and results of the overall performance test, where applicable;
- Acceptance levels;
- Description and location of all recordable indications;
- Test results with reference to acceptance levels;
- Names, relevant qualification and signatures of the personnel who carried out the test.

2.6. Examination with penetrating radiation

2.6.1. Properties of X (röntgen) and gamma radiation I

2.6.1.1. Introductory notions

X-rays and gamma rays are part of the group of electromagnetic radiation, which includes different types of radiation such as light and thermal radiation. Although they have the same nature, they have different properties, such as visibility, which is based on the energy of the radiation. The amount of radiation is characterised by the efficiency of the radiation and is called the H-dose, which can be calculated from the dose rate multiplied by the time it acts on matter. The unit of measure of dose is Sievert, abbreviated Sv.

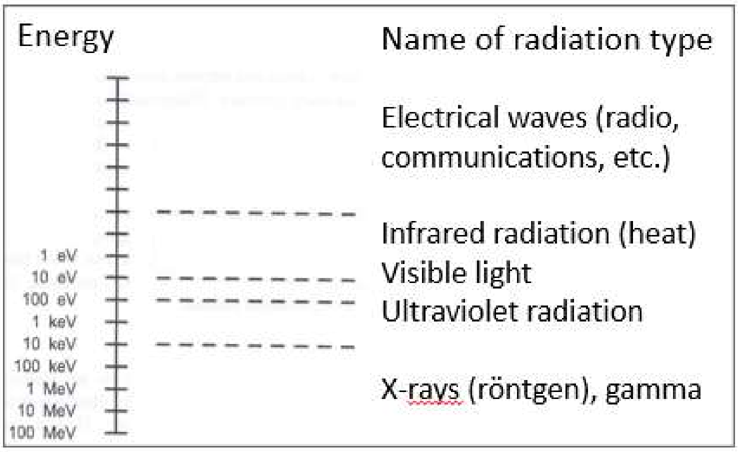


Figure 1

The schematic is the energetically ordered overview of electromagnetic radiation names, usually expressed in electron volts (eV, keV, MeV) and is used to characterize radiation instead of energy and wavelength.

Table 1 - Electromagnetic spectrum values:

Name	Wavelength	Frequency (Hz)	Photon energy (eV)
Gamma ray	less than 10 pm	more than 30 EHz	more than 124 keV
X-ray	10 pm – 10 nm	30 PHz – 30 EHz	124 keV – 124 eV
Ultraviolet	10 nm – 400 nm	750 THz – 30 PHz	124 eV – 3.3 eV
Visible light	400 nm – 700 nm	430 THz – 750 THz	3.3 eV – 1.7 eV
Infrared	700 nm – 1 mm	300 GHz – 430 THz	1.7 eV – 1.24 meV
Microwave	1 mm – 1 meter	300 MHz – 300 GHz	1.24 meV – 1.24 µeV
Radio	1 meter and more	300 MHz and below	1.24 µeV and below

The table represents the electromagnetic spectrum, which shows the frequency range of electromagnetic radiation with the respective wavelengths and photon energies.

2.6.1.2. Production of X-rays (röntgen)

X-radiation production in a röntgen tube is governed by a fundamental natural law - when charged particles like electrons are suddenly decelerated by an obstacle, they lose kinetic energy, a small fraction of which is converted into X-rays that are emitted from the obstacle. The majority of kinetic energy released during deceleration is converted into heat, resulting in a low yield of X-rays, as only about 1% of the total power is converted into röntgen radiation, and the remaining 99% produces heat. Three steps are required for the technical realization of this law - electron production, acceleration, and deceleration against a suitable obstacle. Electrons are produced by applying a heating voltage to a filament that releases electrons, which are then accelerated towards a metal plate, called the anode, through a very high direct voltage. The electrons are then trapped by the anode and produce röntgen radiation and heat, and to prevent the electrons from colliding with air molecules and reaching the anode, the entire system is placed in a vacuum within a glass tube. Tungsten is typically used as the point of impact on the anode due to its high melting point, and the anode must be cooled to prevent weakening of the already produced röntgen radiation.

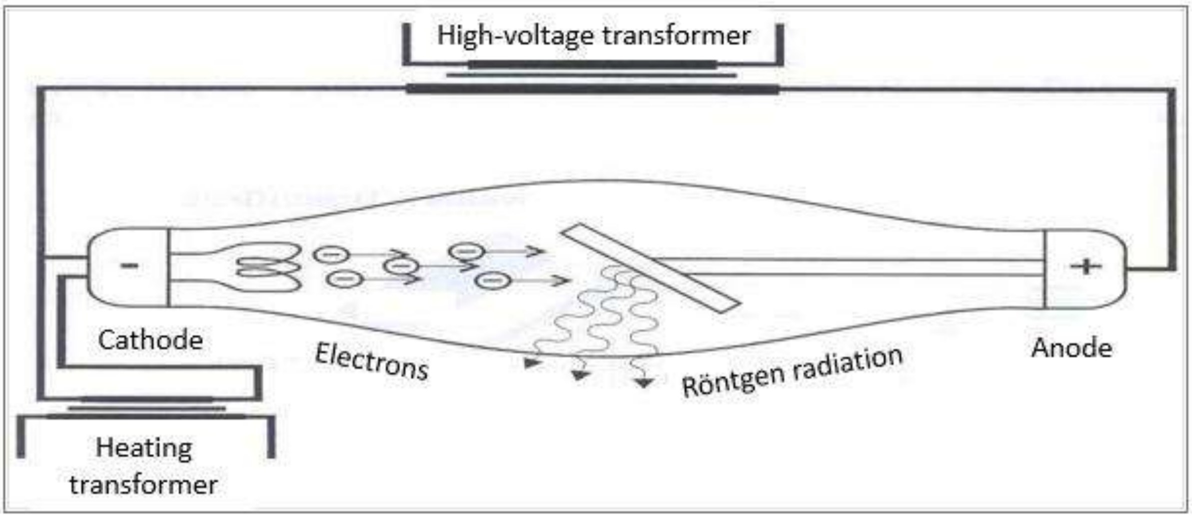


Figure 2

2.6.1.3. Size of outbreak (d)

The electron impact is concentrated in a small area of only a few square millimeters, called the true focus. Because the sharpness of an X-ray image also depends on its size, it is kept as small as possible. By placing the anode obliquely, the true focus produced by the electrons on the anode appears in the direction of radiation output - usually perpendicular to the direction of electron motion - smaller; this projection of the true focus is called the effective optical focus.

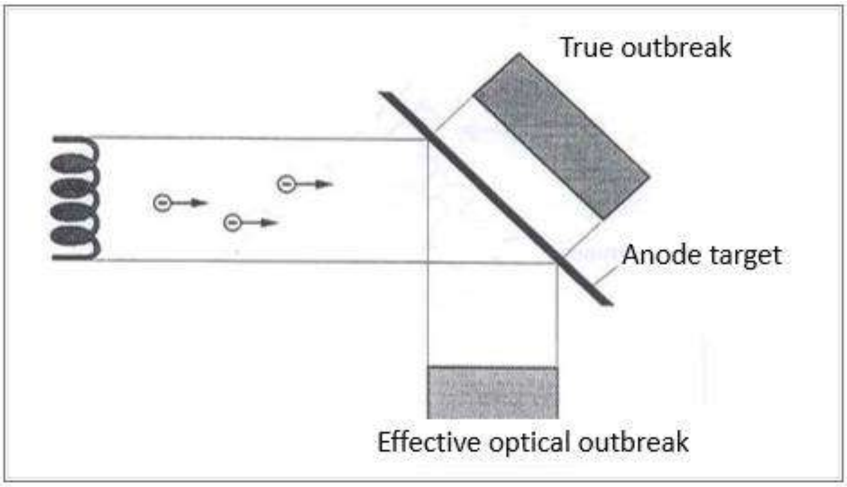


Figure 3

2.6.1.4. Inverse square law

The inverse square law is a fundamental principle that governs how the intensity of radiation decreases as it spreads out from its source. According to this law, the intensity of radiation decreases inversely proportional to the square of the distance from the source. This means that if the distance from the source is doubled, the intensity of the radiation is reduced to one-fourth of its original value. If the distance is tripled, the intensity is reduced to one-ninth, and so on.

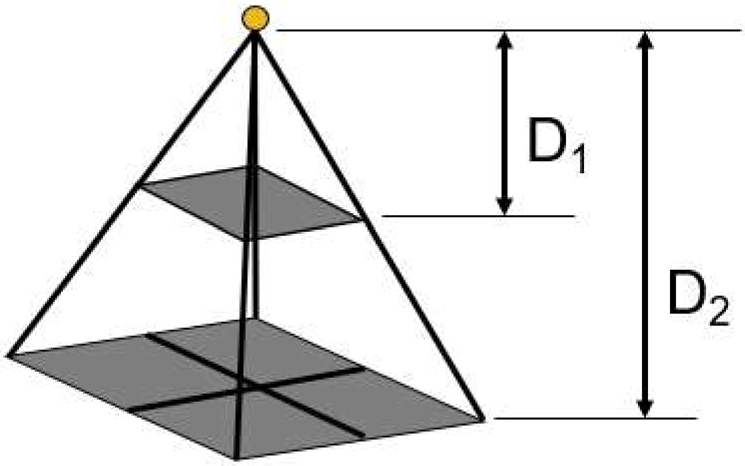


Figure 4

The inverse square law is applicable to a wide range of radiation sources, including light, sound, and electromagnetic radiation such as x-rays and gamma rays. This law plays a crucial role in the design and use of radiation detection and protection systems. For example, it is important to consider the distance between a radiation source and a person or object that needs to be protected from radiation exposure. The inverse square law also has implications in the field of photography, as it governs the way light intensity decreases with distance and affects the exposure of photographs. Overall, the inverse square law is an essential principle that helps us understand the behavior of radiation and its effects on the environment and human health.

2.6.1.5. Braking spectrum

Radiation energy produced in a röntgen tube is limited by the kinetic energy of the electrons, and even though the maximum energy is 100 kiloelectrovolt (keV), in practice, lower energy radiation is produced more easily and more often. The paragraph also explains that a röntgen radiation of 100 kiloVolts means a braking spectrum with a limiting energy of 100 kiloelectrovolt, but the average energy is much lower than the regulated voltage.

When a DC voltage is applied to a röntgen tube, radiation is only produced during a half-period, and the dose rate decreases compared to an AC voltage. However, this half-wave connection is often used because it is technically simple, requires little space, and is light in weight. The paragraph also mentions that more complicated DC voltage connections are built to optimize the intensity-time variation.

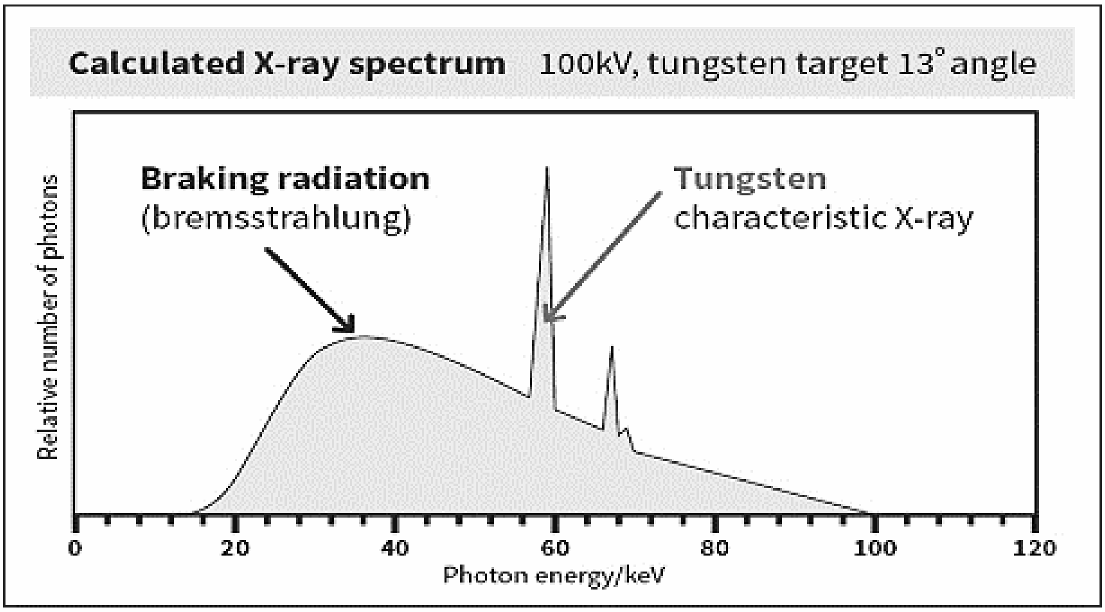


Figure 5

2.6.1.6. Gamma radiation production (Radioactivity, radionuclide, A-activity)

Radioactivity is the emission of radiation from unstable atomic nuclei. These nuclei can be naturally occurring, such as uranium, or artificially induced through the introduction of neutrons into a nuclear reactor. When a radionuclide undergoes radioactive decay, it emits radiation energy as it transforms into a stable state. Radionuclides are identified by their chemical symbol and mass number; and can have varying radiation properties. While the energy of the radiation remains constant, the dose rate of the emitted radiation decreases as the radionuclide decays. The activity of a radioactive substance is measured in Becquerels (Bq), which represents the number of decay events per second. Figure 6 illustrates how the decay rate varies among different radionuclides and can be quantified using the half-life (HWZ) to indicate when a given initial activity (A0) will reduce to half its value. Additionally, the ten times ZWZ reduction time can be used to cover longer time intervals, with 1 ZWZ being equivalent to 3.3 half-life (HWZ).

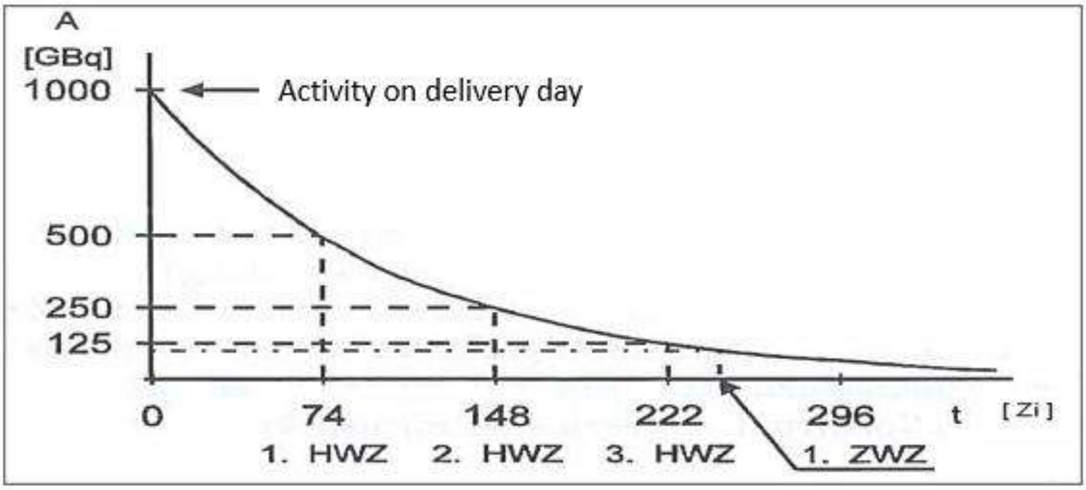


Figure 6

2.6.1.7. E energy

Any radioactive source emits radiation with a certain energy or energy distribution, which cannot be changed because it depends on the type of decay. The possible types of decay or radiation belong to the:

Alpha α radiation: core component equals with helium nuclei 2 Positive

Beta β radiation: positive β means positrons and negative β means electrons

Gamma γ radiation: energy quanta equal to photons

Sources with only one type of decay emit only radiation with one energy component (monochromatic radiation), e.g., Cs137, while others with several types of decay "simultaneously" emit correspondingly more energy components, e.g., Se75, Ir192, Co60. The difference with X-ray radiation (röntgen), however, is that there is no continuous spectrum, but a spectrum of lines.

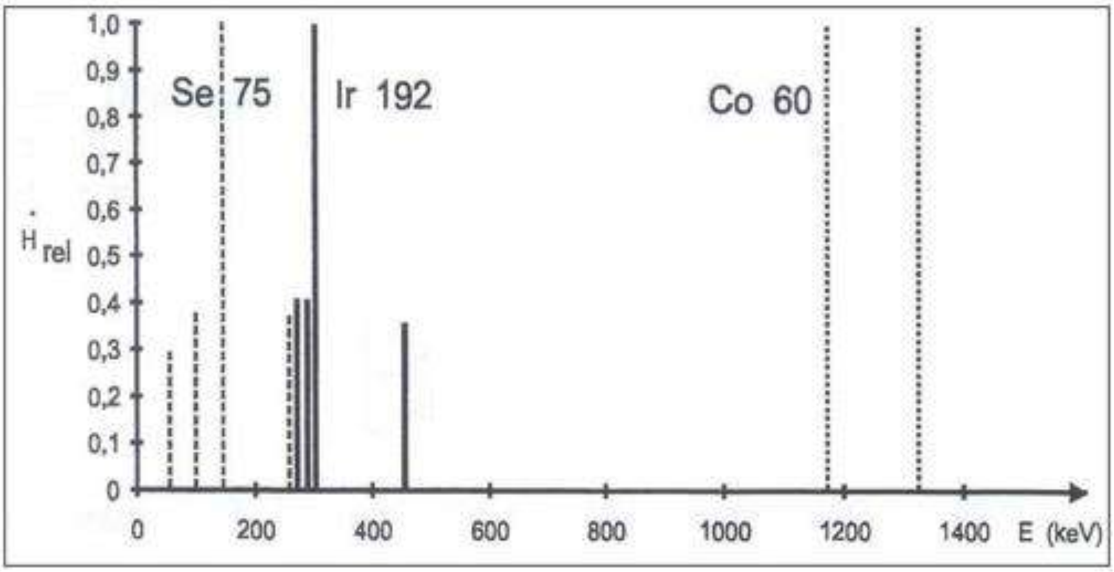


Figure 7

Table 2 - Röntgen energies:

Equivalent röntgen energies	
Nuclide	corresponds to about ... keV
Se75	350 - 500
Ir192	500 - 600
Co60	2000 - 2500

The table shows the equivalent röntgen radiation - characterized by its limiting energy - which has roughly the same representation properties in steel penetrating radiation monitoring as the respective gamma source.

2.6.1.7. Constant of dose debit Γ

The constant dose rate for gamma sources is indicated at a distance of one meter from the source for an activity of 1 Giga-becquerel (GBq), similarly to röntgen sources. This allows for calculating the dose rate for any other activity or distance, following the square law of distance. Gamma sources for technical radiography must have a sufficiently long service life, appropriate energy domain, small sizes at high activity, and an affordable price. Four radionuclides - Co60, Ir192, Se75, and Yb169 - were crystallized, with Ir192 being the most commonly used, due to its favorable energy distribution despite its short half-life of 74 days. Co60 is suitable for thicker parts with a limiting energy between 2.0 and 2.5 megaelectrovolt (MeV) and a longer HWZ of 5.2 years.

Table 3 - Gamma source characteristics

Nuclide	Half-life	Γ_{nuclid} [mSv•m²/h•GBq]
Yb169	31 days	0,049
Se75	120 days	0,055
Ir192	74 days	0,13
Co60	5,2 years	0,35

2.6.1.8. Recapitulation of part one (Properties of X (röntgen) and gamma radiation I)

Gamma radiation always exists when radionuclides (supercharged atomic nuclei) decay radioactively. They appear as artificial radionuclides (reactor neutron activation): like cobalt, iridium selenium and ytterbium; the second are natural radionuclides: like uranium. The characterization of a radionuclide is determined by its chemical symbol and mass number.

Activity A presents an existing substance capable of radiation responsible for disintegration in unit time (Becquerel). The definition of 1 Becquerel is equal to1 disintegration per minus one second [s-1]. Half-life is used to calculate activity, namely the reduction of activity in a given time (depending on the source) to half the value. Ten-fold reduction time refers to reducing activity to one-tenth of the original activity. The dose rate of a gamma source is constant dose rate Γ.

The Characteristic data of a gamma source is:

- its name
- its activity A_0 at a given date
- its half-life
- its dose rate constant Γ
- its focal size d

2.6.2 Properties of X (röntgen) and gamma radiation II

2.6.2.1. Penetration capacity

X (röntgen) and gamma radiation has the highest energy, also capable of penetrating solids to some extent. This penetrating ability is the basis of radiography because it allows an opaque body, such as a welded seam, to become quasi-transparent. A welcome feature here is that the radiation propagates rectilinearly. Figure 8 shows what X (röntgen), and gamma radiation of different energies are usually called. The adjectives 'soft', 'hard', etc. are used to characterize the quality of the radiation, which is directly related to the penetration capacity. Soft radiation has a low penetrating capacity, and hard radiation has a high one; thus, penetrating capacity increases with the energy of the radiation.

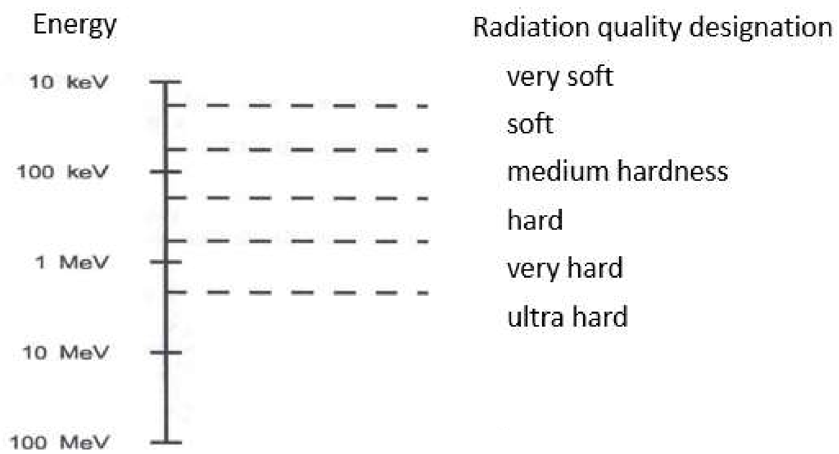


Figure 8

2.6.2.2. X-ray attenuation

X-ray attenuation in soft tissue occurs due to the absorption and scattering of the radiation as it passes through the body, which depends on the density and composition of the tissue.

As radiation penetrates through an object, it undergoes attenuation, causing a decrease in its number. Attenuation takes place due to the absorption or scattering of quanta inside the object. Absorption leads to complete absorption of the radiation, making it almost non-existent, while scattering is like diffused light and results in radiation being dispersed in all directions, making it difficult to view the object from all sides. Scattering can also occur inside the object, producing scattered radiation with lower energy than the primary radiation, which is undesired in technical radiography and needs to be addressed.

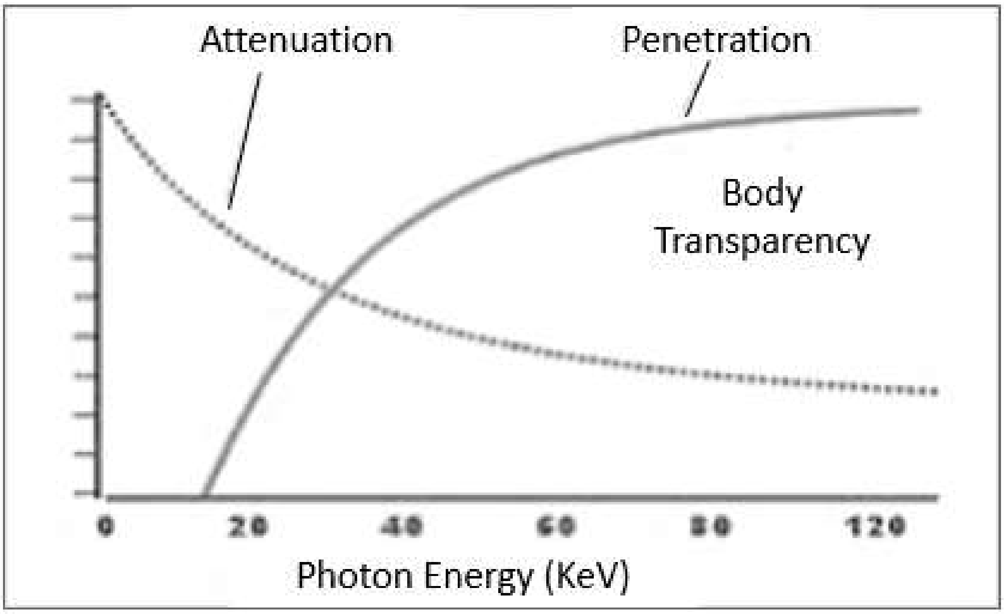


Figure 9

2.6.2.3. Radiation measurement and detection devices

Since humans cannot directly sense X-rays and gamma radiation, they must rely on other means of detection based on their ionizing effect. It is not enough to simply know whether or not radiation is present; it is important to measure and quantify radiation levels in terms of dose rate and dose. This is essential for radiation protection regulations and requires the use of devices such as dosimeters, dose flow meters, and warning systems to measure personal dose, determine protected areas based on dose rates, and quickly detect high dose rates due to equipment malfunction.

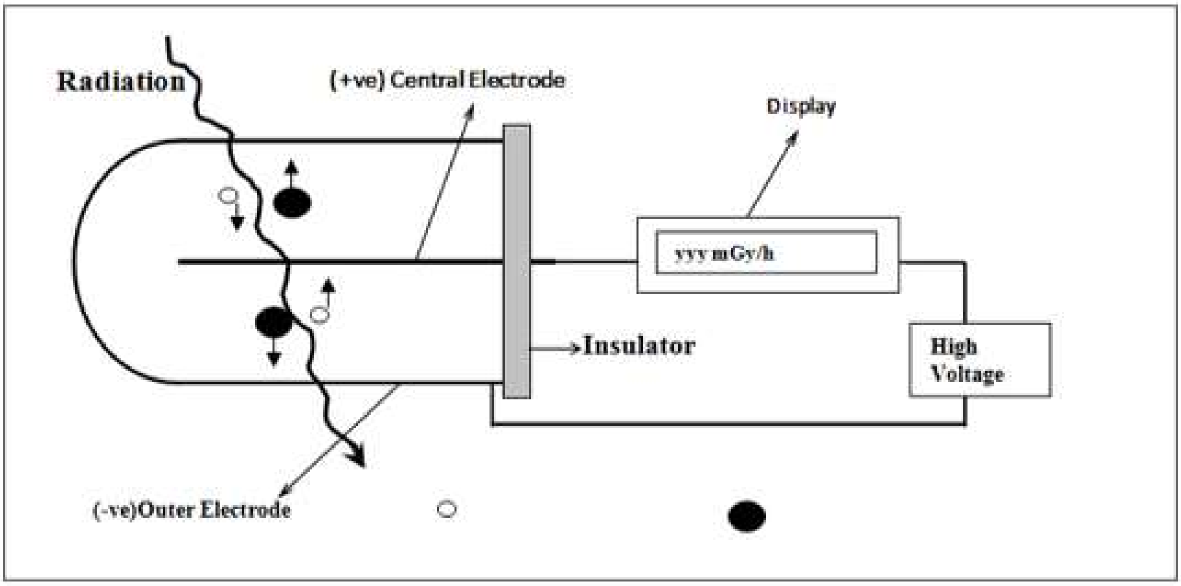


Figure 10

Typically, these instruments comprise two electrodes - an inner one and an outer one - surrounded by an insulator and linked to a high voltage supply, with the radiation displayed as a numerical value on a screen.

2.6.2.4. Dose measurement

The condenser chamber (figure 11) is made out of a glass vessel, two metal parts are positioned at a certain distance from each other, which can be in the form of plates, wires or cylinders; between these two so-called electrodes there is air or another gas. The two electrodes are charged with metal connecting wires through the glass bubble. If röntgen or gamma radiation penetrates the air or gas, the atoms are ionized. Electrons move in the direction of the positively charged electrode, ions in the direction of the negatively charged electrode, a discharge occurs at both electrodes, which can then be observed with a suitable instrument and scale.

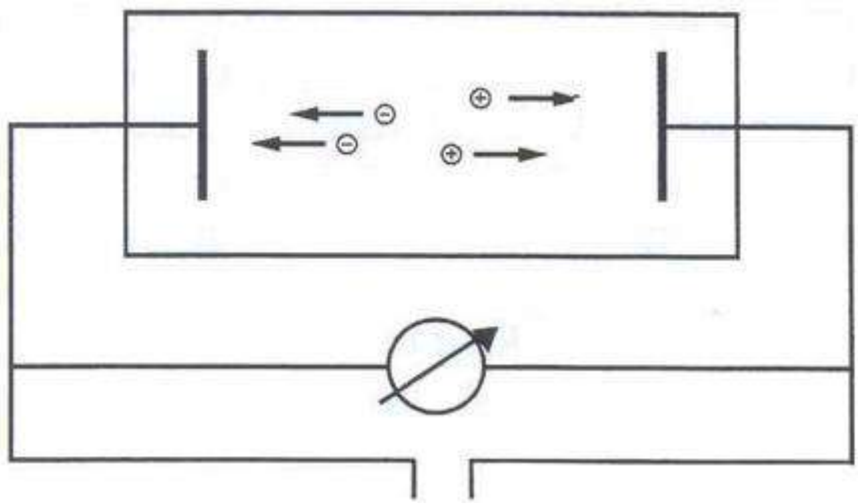


Figure 11

2.6.2.5. Rod dosimeter

Rod or pen dosimeters operate on the principle of electroscope or condenser chamber, and have different measuring ranges depending on the type, typically from 0 to 2000 Sievert.

(Sv), while accident dosimeters can measure up to 6000 Millisievert (mSv). Self-discharge is a known issue with these dosimeters, causing high readings during long-term measurements, but daily readings are typically taken. Additionally, these dosimeters are energy-dependent, and care must be taken to ensure their accuracy in measuring soft X-rays.

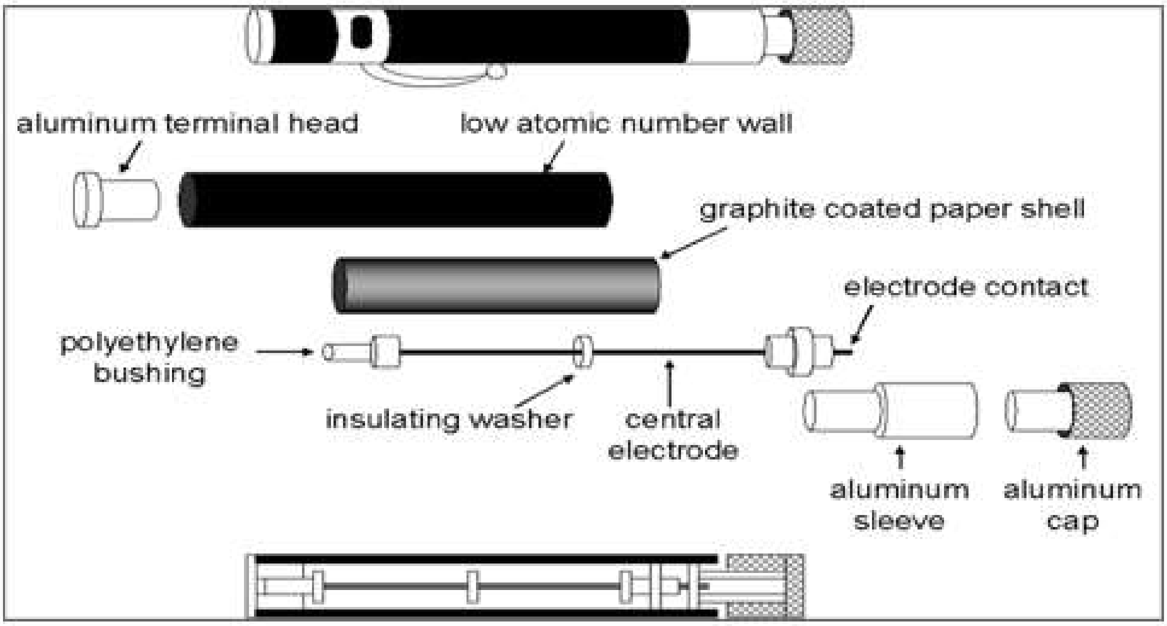


Figure 12

A rod dosimeter (figure 12) is a type of radiation detector that is used to measure the dose of ionizing radiation received by an object or individual. It is a small, cylindrical device that is made of a radiation-sensitive material such as quartz, lithium fluoride, or another suitable material. The material is chosen based on its ability to respond to ionizing radiation by trapping electrons or other charged particles generated by the radiation. The amount of trapped charge is proportional to the amount of radiation exposure and can be measured by a suitable instrument such as an electrometer. Rod dosimeters are commonly used for personal dosimetry, as they are compact, easy to use, and can provide an accurate measure of radiation exposure over a wide range of energies and dose rates. They are also useful for monitoring the radiation environment in areas where radiation exposure may be a concern, such as nuclear power plants or medical facilities that use ionizing radiation for diagnosis or treatment.

2.6.2.6. Film dosimeter

The film dosimeter is a type of dosimeter that utilizes the photochemical effect of X-rays and gamma radiation and consists of two films of different sensitivities. Its optical density can be calibrated using the blackening curve of the film in dose values. However, only officially recognized bodies can assess film dosimeters, as they must determine the dose per body, which requires knowledge of the approximate radiation energy that has blackened the film plate (figure 13).

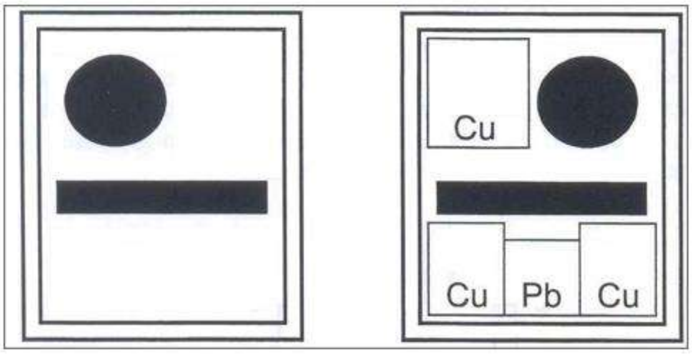


Figure 13

To determine this, the film dosimeter contains filters of different thicknesses and materials that produce different blackening, allowing the estimation of the radiation quality. Film dosimeters are usually evaluated on a monthly basis and have a measuring range between 200 microsieverts (µSv) and 1000 Millisievert (mSv).

The film plate is a type of radiation dosimeter that uses photographic film to measure radiation exposure by analyzing the density of the film after exposure.

2.6.2.7. Dose flow measurement

Dose flow measurement refers to the process of measuring the flow of ionizing radiation in a given space or environment (ionization chamber - figure 14), which is crucial for ensuring radiation safety. This measurement is typically conducted using specialized instruments, such as radiation survey meters or dosimeters, which detect and quantify the amount of radiation present in a given area. By measuring dose flow, radiation workers and safety personnel can determine the potential risk of exposure and take appropriate measures to protect themselves and others from harmful effects. Additionally, dose flow measurements can be used to assess the effectiveness of radiation shielding or containment measures, and to monitor changes in radiation levels over time.

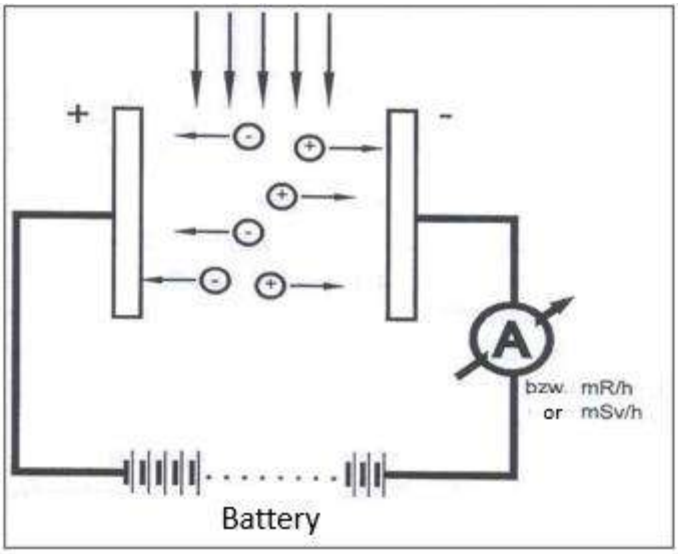


Figure 14

2.6.2.8. Measuring meters

It is important to note that dose flow meters (fig. 15) or counters are important tools for measuring radiation levels in various industries. The amplification effect of the avalanche process can be useful in increasing the sensitivity of these devices, allowing for accurate measurements of low dose rates.

Figure 15

However, it is crucial to use the appropriate device for the specific type of radiation being measured. As mentioned in the passage, counters are more energy-dependent than ionization chamber devices, and they may not be suitable for measuring dose rates from certain types of radiation sources.

It is also important to regularly calibrate and test these devices to ensure their accuracy and reliability. Inaccurate measurements can lead to incorrect conclusions and decisions that may result in serious harm to individuals and the environment.

In summary, while dose flow meters or counters can be effective tools for measuring radiation levels, it is important to use the appropriate device for the specific type of radiation being measured and to regularly test and calibrate these devices to ensure their accuracy and reliability.

2.6.2.9. Dose flow warning device

Portable warning devices (fig. 16) are used to protect against high radiation levels. These devices, also known as Geiger-Müller counters, emit a warning signal (an acoustic and optical signal) when the dose rate exceeds a certain value that can be set on the device. The threshold value should be between 100 Microsieverts per hour (µSv/h) and 1 Millisievert per hour (mSv/h) depending on the model approval. It is mandatory to use these devices when working with gamma-source appliances. However, these devices cannot be used to check whether the radiation source is in the container. Daily checks of the battery voltage and capacity of these devices should be done by keeping them next to a working container with a gamma source. If they do not emit a warning tone, then the battery may be dead, or the appliance may be defective. The warning device must give a clear signal in good time before the battery voltage is interrupted. Portable battery-operated devices in pocket format are commonly used for this purpose.

Figure 16

2.6.2.10. Dosimetry of persons. Basic safe working practice.

Dosimetry of persons is the measurement of the radiation dose that a person receives in a specific period, either from a single exposure or from multiple exposures over time. Dosimetry is important for those working with radioactive materials or in environments with high radiation levels, such as nuclear power plants, medical imaging facilities, and research laboratories. Dosimeters must be worn by individuals to measure their personal radiation exposure or placed in an area to measure the radiation levels in that location. The data collected from dosimetry must be used to ensure that radiation exposure is within safe limits and to identify any areas or activities that may require additional safety measures to reduce exposure.

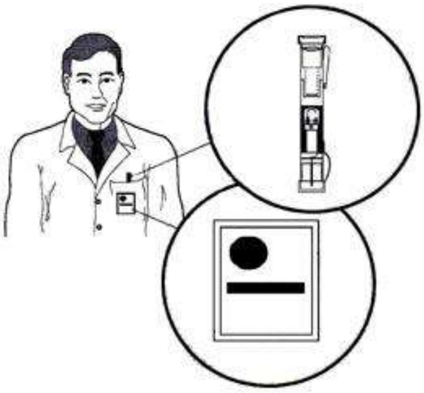


Figure 17

Any of the body tissues may be injured by excessive exposure to x-rays or gamma rays: the blood, the lens of the eye, and some internal organs being particularly sensitive. Unless exposure to x-rays or gamma rays is kept at a minimum, the cumulative effect may cause injury to the body, and it is essential that workers in the radiographic department be adequately protected against radiation at all times. Furthermore, protective measures should be so arranged that persons in nearby areas are also safe. Precautions should be particularly observed when radiography is done in the work areas of the shop rather than in a specially constructed department.

For x-rays, exposure may be caused by the direct beam from the x-ray tube target or by scattered radiation arising from objects in the direct beam. Therefore, while exposures are being made, operators should always be protected by sufficient lead, or its equivalent, shielding them from the x-ray beam, the part being radiographed, and any other matter exposed to the x-rays. All the controls must be located outside the exposure room, or as far as posible from the x-ray tube.

If the object being radiographed is too large or heavy to be brought to the exposure room, the radiography must be done in the shop or on situ. Under such conditions, special precautions are necessary. Collimators on the x-ray machine should be used to confine the x-ray beam to a certain direction and to the minimum angle that can be used. Portable screens should be provided to protect workers nearby. Guard rails or ropes and warnings should be used to keep others at a safe distance.

Most gamma-ray emitters used in industry are artificial radioactive isotopes; the procurement, use, handling, storage, and the like are controlled directly, or indirectly by state radiation control laws approved by the Atomic Energy Commission. It is essential, therefore, that these codes be followed rigorously.

Gamma rays may be very penetrating. For instance, one-half inch of lead reduces the intensity of the gamma rays of cobalt 60 only about 50 percent. This makes the problems of protection somewhat different from those encountered in protection against moderate-voltage x-rays in general, it is not feasible to provide safety from gamma rays solely by means of a protective barrier. Therefore, distance or a combination of distance and protective material is usually required.

Because of the great thicknesses of protective materials required for shielding some gamma-ray sources, distance is the most economical method of protection while the source is in use. A danger zone should be roped off around the location of the radioactive material, and personnel should be forbidden to enter this zone except to put the source in position or return it to its safe. Suitable conspicuous signs should be provided to warn away the casual passersby. Tables are available that give data for calculating the distances from various amounts of radioactive material at which a radiation hazard exists.

In field radiography, protection is usually obtained by distance. Care should always be taken to see that all personnel are far enough away from the radiation source to insure safety.

2.6.3 Attenuation of X (röntgen) and gamma I and II radiation

2.6.3.1. Measurements of influence

The use of röntgen and gamma radiation is impacted by the fact that the dose rate of primary radiation is reduced when it passes through a material, resulting in a lower dose rate measured after the material. This attenuation is affected by several factors, including the radiation energy, penetrated thickness, and material density and composition. Different materials have varying levels of penetration capacity, with low atomic weight and density materials being classified as soft radiation and high atomic weight and density materials as hard radiation.

Attenuation occurs through absorption and scattering of radiation, which can alter its direction and reduce its energy. The half-value layer thickness is used to measure the attenuation effect of a material, with higher energies resulting in greater attenuation. The degree of attenuation can be described using the attenuation factor FN.

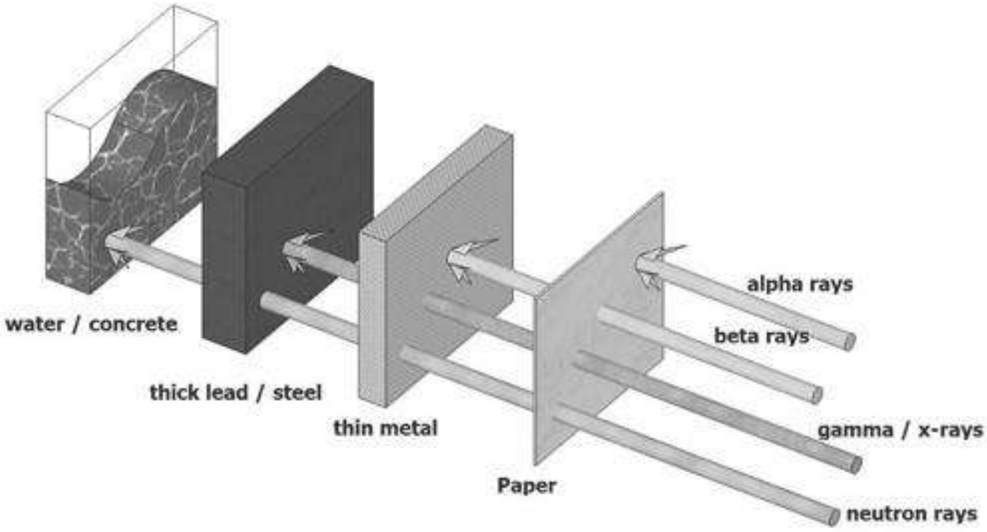


Figure 18

2.6.3.2. Construction and servicing of röntgen installations

The construction and servicing of Röntgen installations require specialized knowledge and training due to the potential hazards associated with radiation exposure. Proper installation, calibration, and maintenance of equipment, as well as strict adherence to safety protocols, are essential to ensure the safety of both patients and operators. Regular inspections, testing, and certification of equipment by qualified professionals are necessary to ensure compliance with regulatory requirements and to minimize the risk of malfunctions or accidents. Additionally, ongoing education and training for operators and technicians are important to stay up-to-date with the latest advancements and best practices in the field.

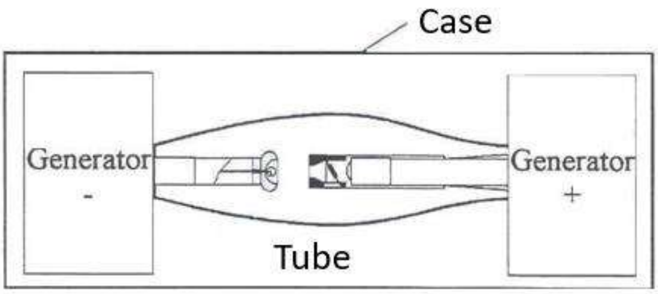


Figure 19

Single tank röntgen installations (fig. 19) are typically designed for portable or mobile use and are commonly used in veterinary medicine or for on-site industrial inspections where a stationary installation is not feasible. They are generally smaller and less powerful than stationary installations, but still require careful handling and maintenance to ensure safe and effective operation.

2.6.3.3. Direct voltage installations

Direct voltage installations are electrical systems that operate using a constant voltage level, usually provided by a direct current power source. Such installations are commonly used in various applications, including electroplating, battery charging, and welding, where a steady and consistent voltage supply is required. Direct voltage installations are generally simpler and more efficient than alternating current systems, as they involve fewer components and require less energy to maintain a constant voltage. However, they may also require specialized equipment and safety measures to prevent electrical shock and other hazards.

Figure 20

2.6.3.4. Half-wave DC installations

Half-wave direct current (DC) installations are a type of electrical circuit that is commonly used in a variety of applications. In a half-wave DC circuit, the current flows only in one direction, resulting in a pulsating DC output waveform. This type of circuit is simple and cost-effective, making it a popular choice for many applications such as battery chargers, power supplies, and electroplating processes.

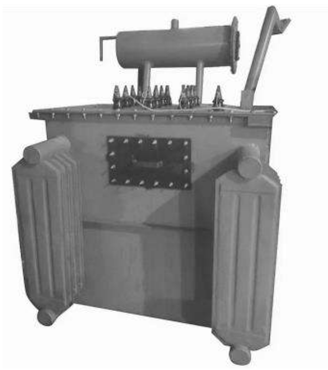


Figure 21

However, it is important to note that half-wave DC circuits have some limitations. For example, they are less efficient compared to full-wave DC circuits, as they only use half of the input power. Additionally, the pulsating nature of the output can cause unwanted noise and interference in sensitive electronic systems.

Despite these limitations, half-wave DC circuits remain a valuable tool in many industries and are often used in applications where cost and simplicity are more important than efficiency and waveform quality.

2.6.3.5. Types of röntgen tubes

Different types of tubes exist depending on the construction of the X-ray apparatus and its intended use. The metal-ceramic model can handle up to U = 420 kiloVolts and I = 10 milliamperes (at Umax). The roentgen radiation is attenuated on its way from the focus to the exit of the tube housing due to the anode construction, glass bubble, cooling medium, and exit window. The röntgen radiation is also filtered or hardened, roughly equivalent to an aluminum layer several milimeters thick. For using soft radiation fractions, a beryllium window tube is required, which allows the radiation to exit almost unfiltered, resulting in a higher dose rate than self-filtering tubes. In all röntgen tubes, radiation is produced in all directions when electrons impact on the anode, but only a certain fraction is used for penetrating radiation control. Most röntgen devices have several diaphragms to adjust the radiation field at the object to be controlled, minimizing scattered radiation.

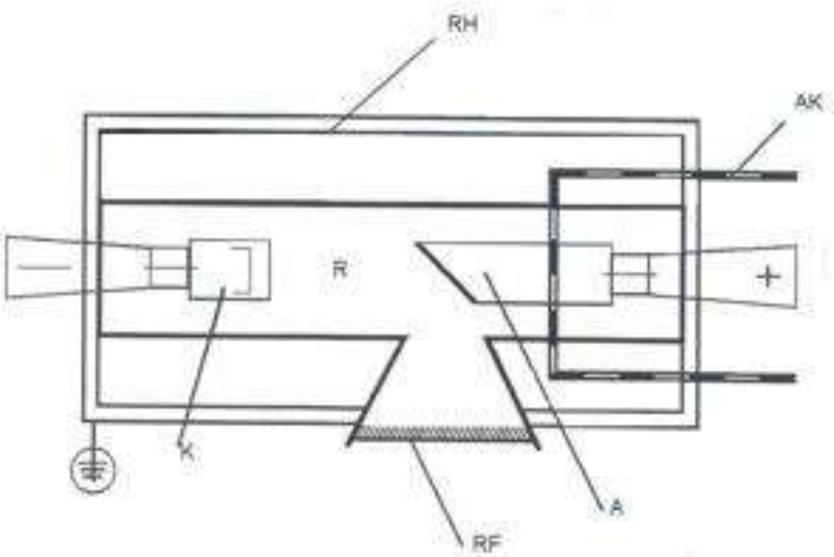


Figure 22.a: Bipolar tube

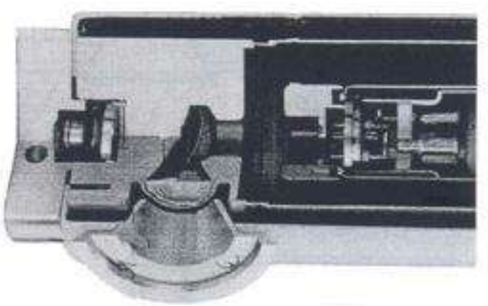


Figure 22.b: Section through short anode tube (160 kV)

Figure 22.c: Diaphragms

2.6.3.6. Servicing röntgen installations

The control panel, also known as the service unit, typically comprises of a main switch, adjustment knobs, and indicating instruments for tube voltage, tube current, and warning exposure time. A flashing warning lamp, which only activates when radiation is being produced in the tube, must remain connected at all times. For X-ray installations designed for stationary use in X-ray rooms, there is an additional contact, allowing for connection to the door contacts of the X-ray room. The door contact ensures that when the door is opened, the voltage to the X-ray tube is automatically disconnected. In X-ray spaces without doors, which are often accessed via a labyrinth, a light barrier can be used in place of a door contact. Due to variations in the control desks, it is important to consult the appliance manufacturer's operating instructions. It is crucial to adhere to the heating requirements for commissioning after extended periods of inactivity.

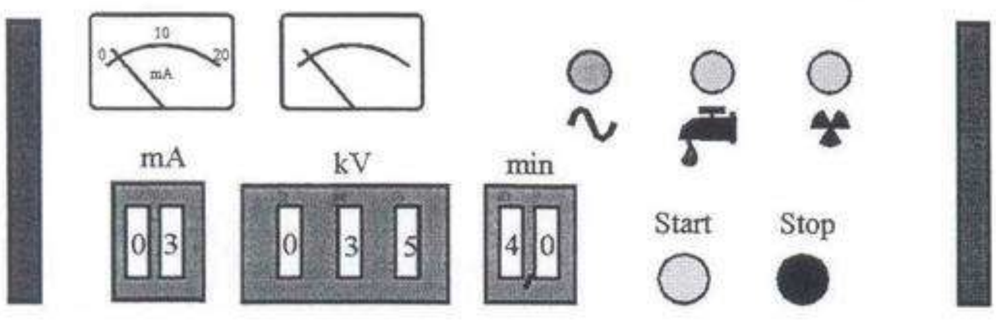


Figure 23

2.6.3.7. Construction and servicing of gamma radiation devices

Gamma radiation devices (fig. 24.a) are simpler in construction and more compact compared to roentgen devices, as they are primarily mechanical handling devices. The primary function of these devices is to screen radioactive material in both the rest and working positions to generate a radiation beam of either conical or annular shape.

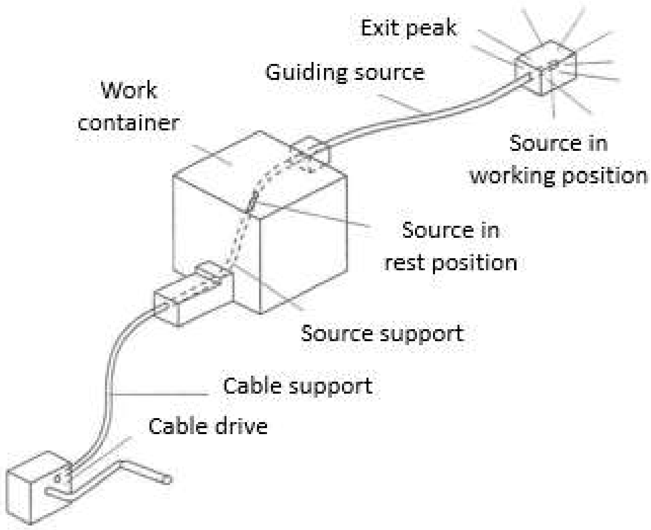


Figure 24.a

The radiation machine comprises a closed radiation source, a source holder, a working container, a remote control (consisting of a cable, cable holder, and cable drive), a source guide (consisting of an output hose and or output tip), and accessory parts such as diaphragms and collimators.

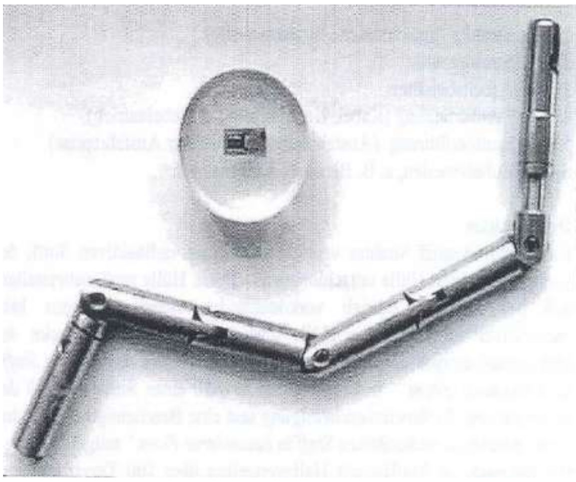


Fig. 24.b

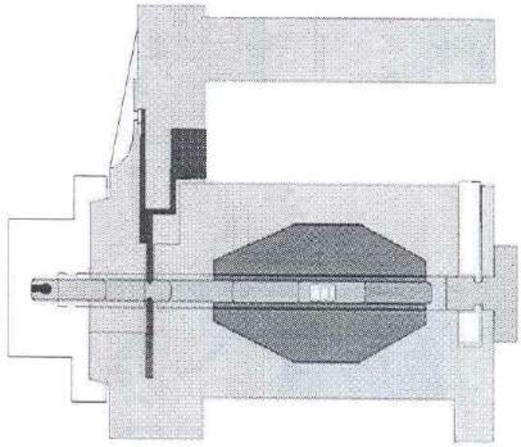


Fig. 24.c

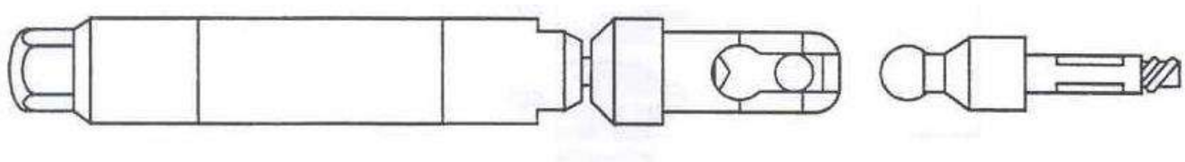


Figure 24.d

The source is a radioactive material enclosed in a sealed envelope to prevent the release of radioactive material during operation. Only "specially enclosed radioactive material" is relevant for radiation monitoring purposes. A certificate of leak-tightness and a certificate of "special form enclosed radioactive material" must accompany the source when purchased. The source holder has two links made of tungsten that serve as radiation protection. The working container is the actual screening container made of tungsten or depleted uranium for shielding. Depending on their weight, size, and mobility, the working containers are divided into P or M classes. Safety devices must be installed to prevent unauthorized persons from opening the appliance and to prevent the source from falling out of the appliance when the remote control is disconnected. The working container must have a Type A or Type B permit for transport on public roads. The type B container must be able to withstand the stresses that may occur in a transport accident. The remote control is used to bring the source holder and source from the working container into the working position. The source guide safely guides the source from the working container to the working position, while accessory parts include extraction hoses of various lengths, extraction tips of various lengths, diaphragms, collimators, and centering devices. Collimators are available in different versions depending on the exposure arrangement. The degree of attenuation FN is between 50 and 100. Maintenance of gamma radiation devices is more comprehensive than for roentgen installations, and the operator and the manufacturer of the device must carry it out. Manufacturers must perform maintenance annually according to the model handling approval, and each gamma working device, including all accessory parts used, must be checked every three years by an expert examination. Possible sources of defects include incorrect handling, poor care and maintenance, and some of these sources of defects include activity or source size, source coating defects, source cladding or source holder joint, and joining the source holder pins. Parts of radiation devices must be durably and unambiguously marked for identification purposes, especially for maintenance and inspection.

2.6.3.8. Film and foil properties

A roentgen film consists of a thin transparent backing material with a radiation-sensitive emulsion layer applied on both sides. The emulsion is made up of gelatin and silver bromide granules. When radiation passes through the film, it ionizes the silver bromide grains, leaving a latent image on the film. After chemical processing, the film contains the complete image of the object that was penetrated by radiation. The remaining silver embedded in the gelatin and backing film absorbs light, causing the film to appear dark or black. The more radiation that penetrates the film, the lighter it appears, resulting in greater blackening of the film. Film exposure causes a dose-dependent density of the grains developed on the film. This is called optical density or blackening.

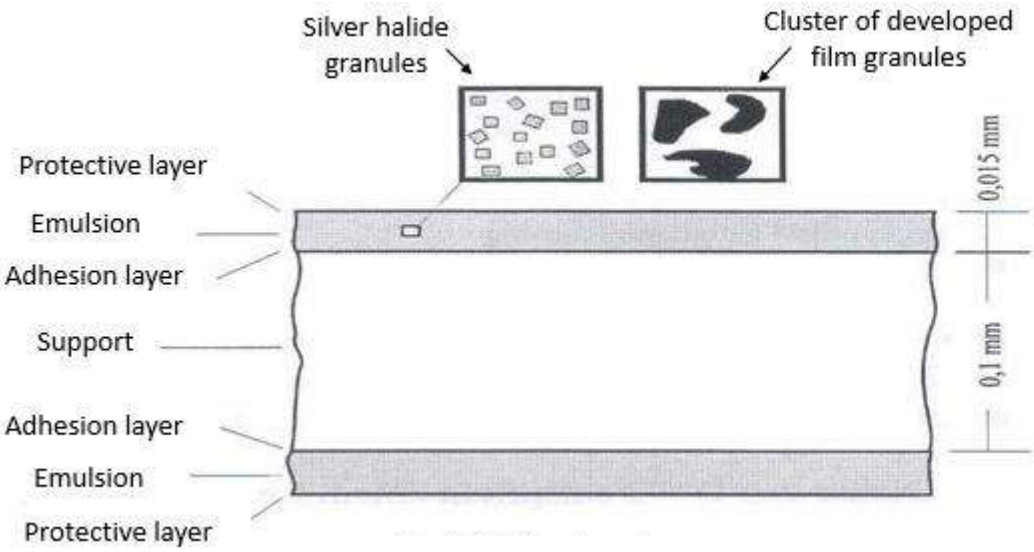


Figure 25

Roentgen foil is a type of detector that can be used to measure radiation exposure. It typically consists of a thin, flexible layer of plastic or other material with a thin layer of metal, such as aluminum or copper, on both sides. When radiation passes through the foil, it interacts with the metal layers, creating an electrical charge that can be measured. The amount of charge generated is proportional to the amount of radiation that passed through the foil. Roentgen foils are often used for personal dosimetry, where they can be worn by individuals to measure their exposure to radiation in various settings. They are also used in medical imaging and radiation therapy to ensure that the correct amount of radiation is delivered to the intended target.

2.6.3.9. Optical density measurement

When measuring the optical density of a radiographic film, a densitometer (fig. 26) is used to obtain two measurements: L0, which is taken without a film to zero the measurement, and LF, which is taken with the film. However, when using a negatoscope as a light source, caution should be exercised as the L0 values on the screen may differ.

Densitometers must be verified with certified "blackening steps." The contrast of the film, which is expressed as $\Delta D = D2 - D1$ (D2/D1), depends on the dose rate of the incident radiation, and contrast is more visible with higher blackness. A doubling of blackness results in a doubling of contrast. While the blackening should increase with the exposure, economic considerations must also be taken into account. Film granularity, which is determined by the size and distribution of the grain clusters, affects detail visibility and is referred to as film graininess. A compromise between graininess and sensitivity is required when selecting a suitable film to highlight certain defect sizes. Films are classified into six categories based on their grain size and contrast sensitivity, with C1 being the finest-grained film with the longest exposure time and C6 being the coarsest-grained film with a shorter exposure time.

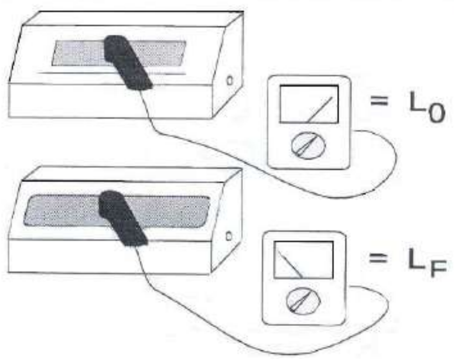


Figure 26

2.6.3.10. Internal Unclarity (u_i)

Internal uncertainty (fig.27), represented as ui, arises from the fact that ionization from radiation passing through a film layer can affect silver bromide grains not only directly in its path but also those further away, resulting in blurred images of sharp edges. The extent of this internal blurring is greater with higher energy radiation.

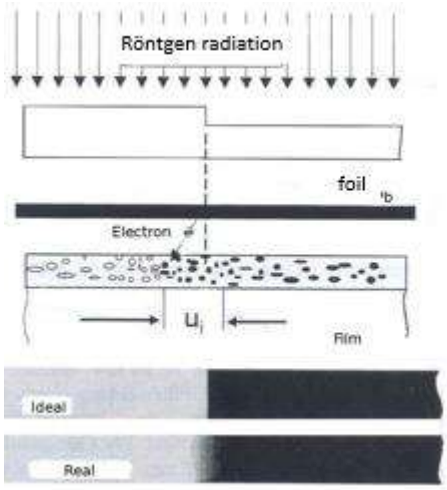


Figure 27

To protect against external light, roentgen films are packaged in cassettes or casings made of special plastic film or PVC films with aluminum boxes.

These cassettes must also provide protection against mechanical damage, moisture, heat, etc. and ensure close contact between the film and foils. Poor adhesion between the film and foils can reduce contrast and increase internal blurring, leading to the loss of fine image details. Vacuum packaging is the best way to ensure excellent film-foil contact and can be done in a darkroom with a suitable apparatus or purchased as a pre-packaged film-foil combination from film manufacturers.

Table 4 - Values for internal fuzziness

	Röntgen radiation					Gamma radiation		
	100 - 250 kV		250 - 420 kV			Ir`92	Co60	
Foil	without	Pb	Pb	salt[1)]	salt[2)]	Pb	Pb	Fe
u_i [mm]	0,08	0,13	0,15	0,3	0,4	0,23	0,6	0,4

1) drawing exactly; 2) intensifying a lot

2.6.3.11. Film processing area

The adequate provision of radiographic services relies heavily on the location, design, and construction of x-ray processing facilities. These facilities can be a single room or a series of rooms dedicated to individual activities, depending on the volume and nature of the work involved. As these rooms play a crucial role in handling, processing, and storing x-ray films, careful consideration should be given to their general and detailed features. Proper planning and foresight in designing these facilities can result in improved production, ease of operation, and reduced maintenance costs.

Efficient processing of x-ray films, from the radiographic room to the viewing room, requires a simple and smooth workflow with minimal steps. The location of the processing room or rooms within the department, as well as the arrangement of equipment, can help to expedite this routine.

Ideally, processing rooms should have filtered air supply at a pressure higher than that of the outside environment, especially if the outside air is prone to contamination by particles like sand or dirt.

The volume of films to be processed and the need for rapid access to finished radiographs determine whether manual or automatic processing is appropriate. In cases of small or intermittent workloads, a single room containing all necessary facilities can suffice. (See Figure 28). However, in cases of relatively high manual processing volume, the process can be expedited by dividing operations into three areas: a room for loading and unloading cassettes, a processing room with a through-the-wall tank, and a washing and drying room.

In general, the manual processing room should be spacious enough to accommodate all necessary equipment without being overcrowded. Future expansion needs should be anticipated, but excessive floor space is not necessary. The room depicted in the figure below can process over 200 films daily and can be constructed within a 9.5 x 15 feet floor space.

Ideally, the processing area should adjoin the exposure room to ensure efficiency. However, in cases where highly penetrating radiation is used, the cost of shielding to protect personnel and film may be prohibitively expensive. In such cases, the processing room should be located at a safe distance from the exposure room.

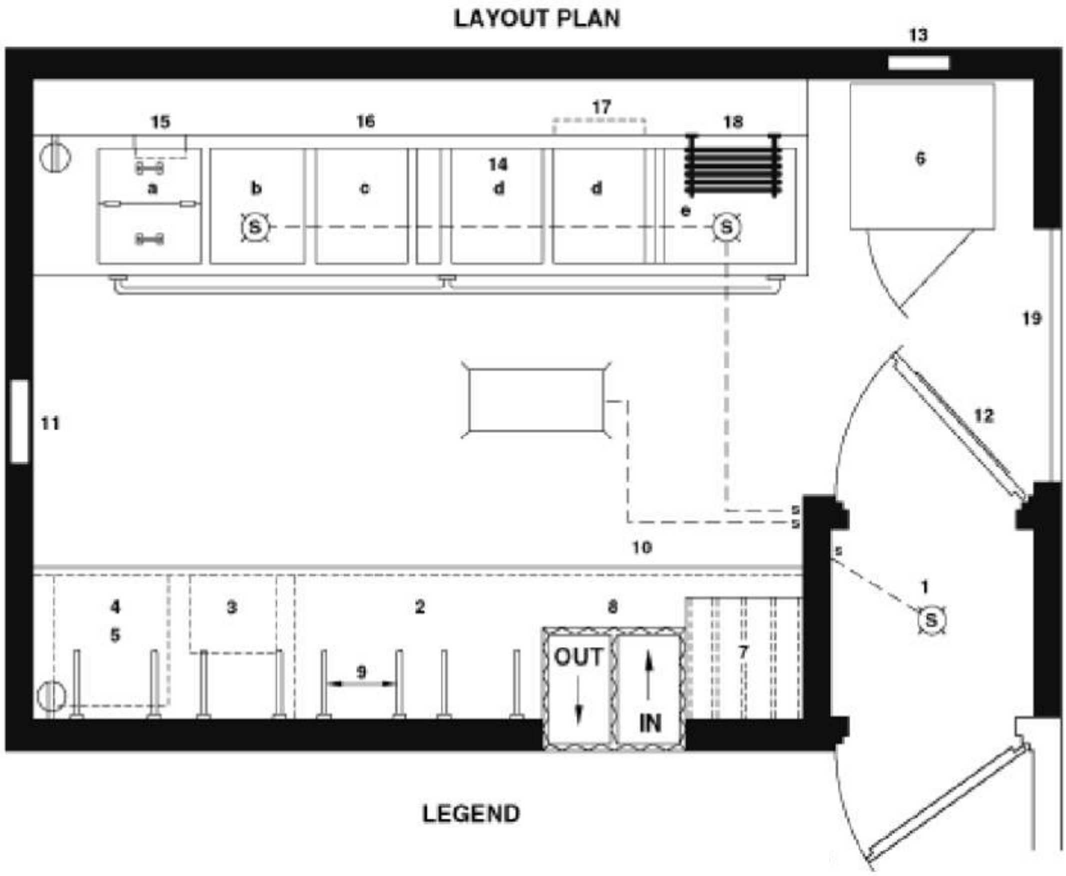


Figure 28

LEGEND

1. LIGHT LOCK WITH LIGHTTIGHT DOORS
2. LOADING BENCH
3. FILM STORAGE BIN
4. LIGHTTIGHT DRAWER
5. WASTE BIN
6. FILM DRYER
7. CASSETTE AND FILM HOLDER STORAGE
8. PASS BOX
9. FILM HANGER RACKS
10. SUPPLY CABINET
11. AIR SUPPLY DUCT
12. LIGHTTIGHT LOUVRE
13. AIR EXHAUST FROM FILM DRYER
14. X-RAY PROCESSING TANK
    a. DEVELOPER
    b. STOP BATH
    c. FIXER
    d. WASH (CASCADE)
    e. SINK
15. ELECTRIC TIMER
16. CHART BOARD
17. ILLUMINATOR
18. DRAINAGE RACK FOR HANGERS
19. LIGHTTIGHT ACCESS PANEL

▭ INDIRECT SAFELIGHT LAMP

Ⓢ DIRECT SAFELIGHT LAMP

⊖ CONVENIENCE OUTLET

S SWITCH

2.6.3.12. Automated processing darkroom

Moving on to the Darkroom Construction: A darkroom should be located away from areas with ionizing radiation, as unexposed films are often stored there as well. It is essential that no light enters the darkroom, as films are blackened by light. The entrance to the darkroom depends on the available space and can be designed as a corridor, swing door, or labyrinth entrance. The lighting of the darkroom should be appropriate and typically consists of red or green light to avoid additional blackening of the films during processing. A separate dry and wet area is preferable, but if only one area is available, an automatic developing plant is recommended.

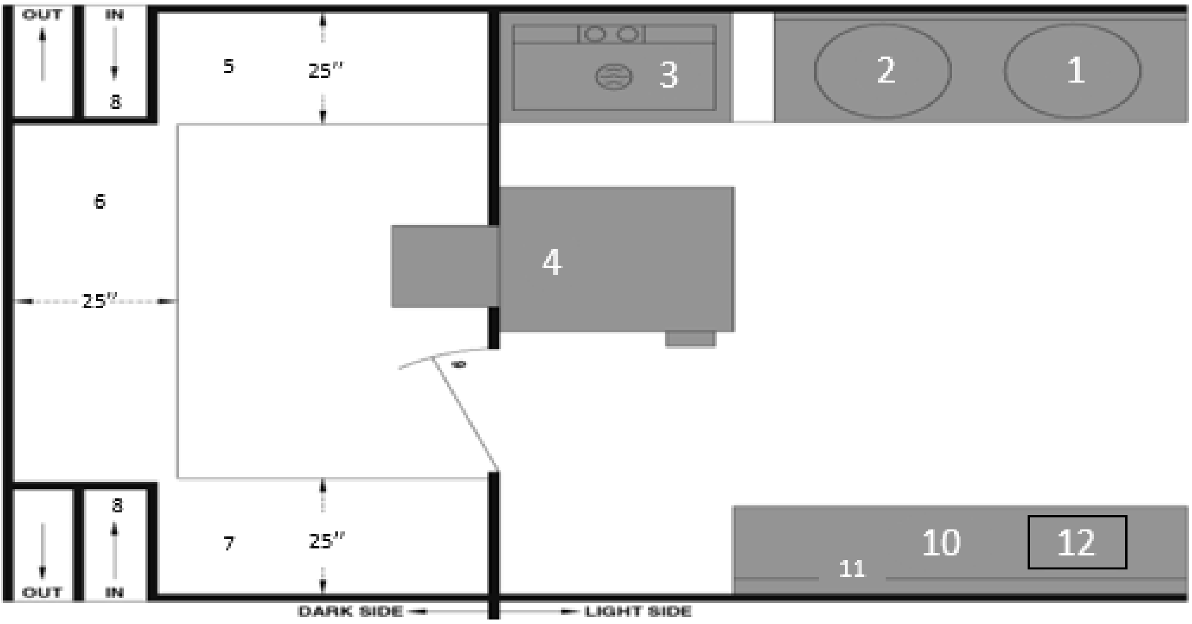


Figure 29

LEGEND

1, 2. CHEMICAL STORAGE TANKS
3. SINK (WAIST HIGH)
4. PROCESSOR
5, 6, 7. BENCH – WORK AREA
8. PASS BOXES
9. ENTRANCE
10.SORTING TABLE
11.ILLUMINATORS
12.DENSITOMETERS

To make the latent image visible, exposed films must be chemically processed according to the film manufacturer's specifications. The regeneration of the developer should also be considered, and the chemical activity and liquid level of the baths should be checked regularly.

Maintaining cleanliness is essential throughout the entire film processing, which involves developing, intermediate washing, fixing, final washing, drying, and automatic developing. Fully automatic developing machines are now commonly used to replace manual film processing, and it is crucial to follow the manufacturer's specifications for servicing and maintenance.

There are general rules for film treatment, including keeping the working area dry and dust-free when packing or unpacking films from cassettes, avoiding excessively wet hands and fingernail prints, not bending the cassette containing the film, and providing enough space between films in the drying cabinet to prevent them from sticking together. Failure to follow these rules and recommendations from film suppliers can lead to film defects that make it difficult or impossible to interpret the films.

2.6.3.13. Film processing summary

Traditional film processing is the method for developing photographic film. The film is initially coated with silver bromide granules, which are light-sensitive. When the film is exposed to light, the silver bromide granules in the areas of the film exposed to light become ionized, which allows them to be removed in the development process.

The developing photographic film process can be broken down into several key steps:

1. Preparation: you need to Gather all the necessary materials, including the film, developer solution, stop bath solution, fixer solution, and a tray or tank for processing the film.

2. Loading: load the film into the processing tank in complete darkness. This can be done using a film loader or by carefully placing the film into the tank.

3. Development: Pour the developer solution into the tank and agitate the tank gently for the recommended amount of time, typically several minutes. The developer will cause the latent image on the film to become visible.

4. Stop Bath: Pour the stop bath solution into the tank to halt the development process. Agitate the tank for the recommended amount of time, typically about 30 seconds.

5. Fixing: Pour the fixer solution into the tank and agitate for the recommended amount of time, typically several minutes. The fixer will dissolve the unexposed silver halides on the film and make the image permanent.

6. Rinsing: Rinse the film thoroughly with water to remove any remaining traces of chemicals.

7. Drying: Hang the film to dry in a dust-free environment. Avoid touching the surface of the film to prevent fingerprints or scratches. Once the film has dried, it can be cut into individual frames and mounted or scanned for digital use.

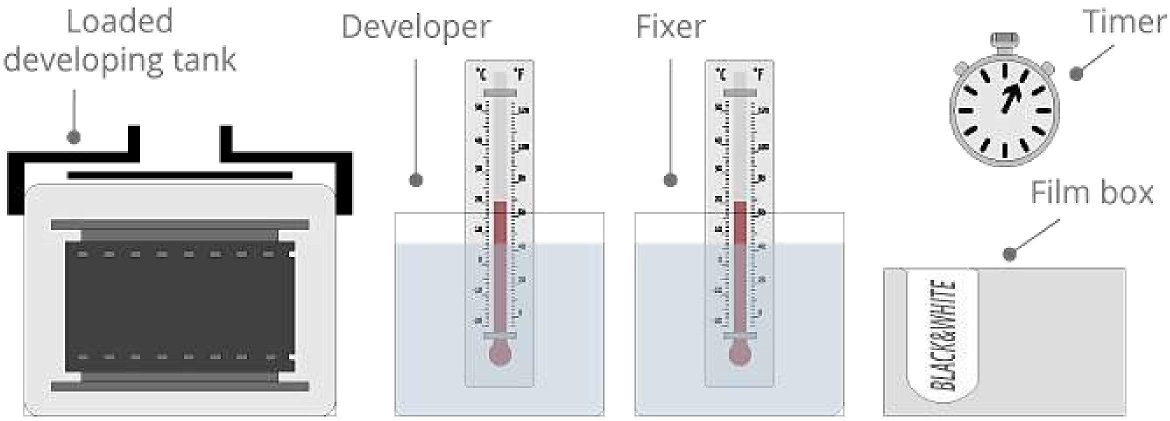


Figure 30

2.6.3.14. Auxiliary means for penetrating radiation monitoring

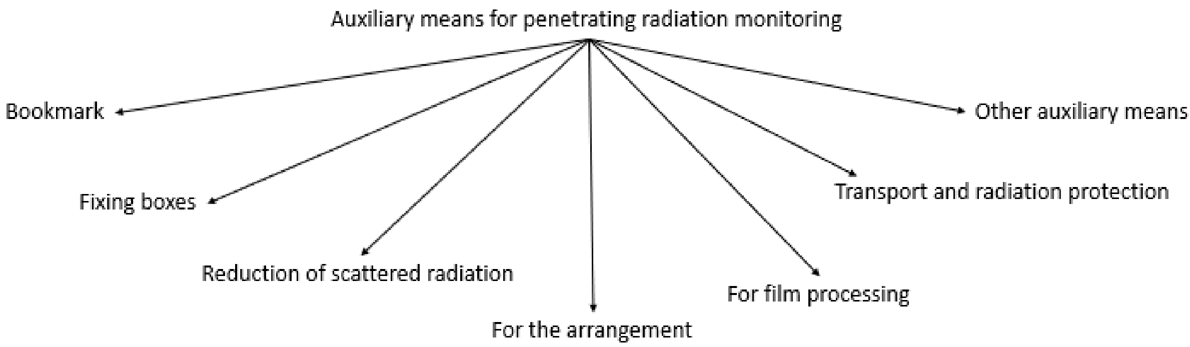


Figure 31

To ensure clarity and avoid confusion, it is essential to mark films unambiguously during exposure using symbols such as numbers, letters, or signs. These symbols are usually irradiated onto the object and visible on the finished film. Lead or plastic plates with a heavy metal insert can be used, and punches can be used to make these symbols from 0.5-1 mm thick lead sheets. Magnetic fasteners or adhesive tape can be used to fix the symbols. For larger parts like circular welded seams on boilers, a radiographic roulette with lead figures known as Wulff's roulette can be used.

To fix the cassettes to the piece, magnets, rubber strips, and film tapes are used. Measures to reduce scattered radiation must be taken by using lead diaphragms, collimators, and filters of lead, tin, or copper. A folding metre is usually necessary for the display arrangement, and exposure rulers and clocks are necessary auxiliary means during exposure and processing. Image quality indicators (IQI) are used to check the contrast obtained, and film gripper frames are required for processing exposed films in a manual developing plant. Drying cabinets of different types and sizes can be used for drying films.

Special negatoscopes with matte screens are required for the interpretation of dry films. Neon tubes or halogen bulbs are used to illuminate these screens. Densitometers are used to determine blackening. Warning signs, fire extinguishers, chalk, dose flow meters, sealing tapes, and chains are necessary auxiliary means for transportation and radiation protection.

2.6.3.15. Basics of representation technique. Contrast

Fundamentals of Representation Technique and Geometric Fuzziness

Representation technique involves projecting the shadow of an object onto a film using penetrating radiation. The resulting image shows not only the edges but also differences in thickness and density, such as cavities and inclusions. Areas with less material penetration, such as cavities, show a lower attenuation of primary radiation, leading to a higher dose rate and stronger blackening of the film. This difference in blackness is known as contrast, which must meet a minimum amount for the eye to perceive it. Rules and standards have been introduced to maximize contrast in X-rays, particularly for cavities, which are better represented the greater their extent in the direction of radiation.

However, flat imperfections like cracks oriented obliquely to the irradiation direction may not produce enough contrast on the film to be perceptible. In such cases, it is beneficial to reorient the irradiation direction after the maximum extent of the defect to increase the contrast. However, this method results in distorted representations of the whole piece.

Geometric fuzziness, or the marginal blurring of an image due to finite expansion radiation sources, also affects the representation technique. Geometric blur is reduced when the radiation source is smaller, further away from the object, and closer to the plane of representation (film). The limiting value for geometric blur is the internal blur of the film material. Therefore, the film must adhere as tightly as possible to the part, and the exposure arrangement must ensure that the surface of the part furthest from the film is still represented clearly.

In summary, geometric sizes of influence on the representation technique include geometric blur, focal size, distance from focus to control range, distance from film to focus, and film-focus distance. Geometric fuzziness can only be influenced by the distance from focus to control range or film-focus distance. Total blur is a combination of geometric and internal fuzziness, with contrast and grain size also affecting defect perception. Most measures to improve the penetrating radiation inspection technique aim to enhance contrast or reduce geometric blur.

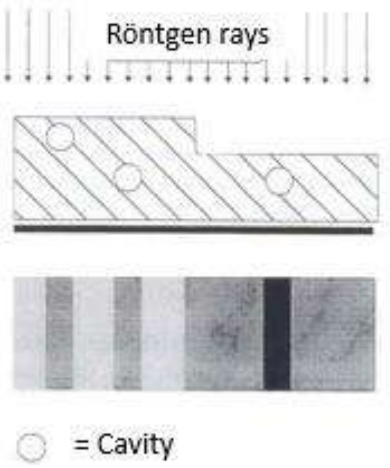


Figure 32

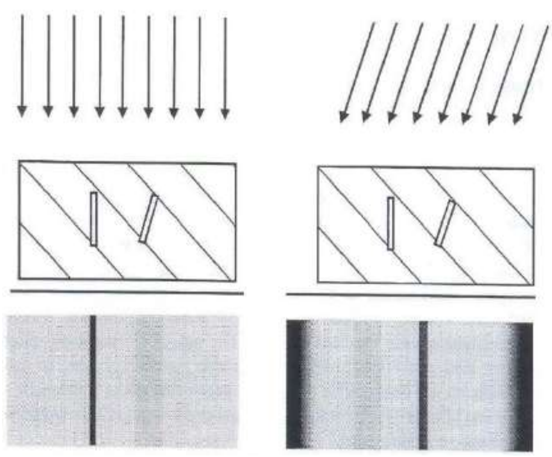


Figure 33

2.6.3.16. Exposure diagrams

Exposure Diagrams: Exposure diagrams offer a practical way of representing the complicated link between the properties of the object being controlled (such as material and thickness) and the exposure data required to achieve a specific level of blackening for different types of film. These diagrams are available for both gamma sources and röntgen installations. Typically, the irradiated thickness (w) of a material, such as steel, is listed against the exposure (B) necessary to achieve a blackening level of D (usually D = 2 or D = 2.5) for a given film type. This is shown as a function of the FFA distance for röntgen installations, or as a function of tube voltage U (kV) for gamma sources. The required film dose can be determined using the formula: required film dose = dose rate - exposure time. This relationship can be expressed as BkV = ItB [mA min] for röntgen installations, or Bnuclid = AtB [GBq min] for gamma sources.

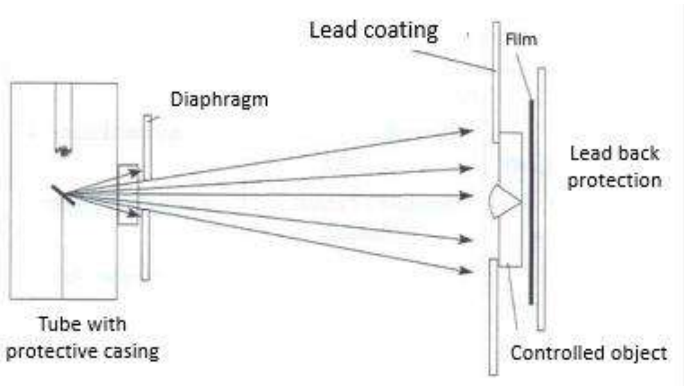


Figure 34

Contrast: Radiation energy has a significant impact on the contrast of an exposure arrangement. Lower radiation energies result in higher contrast, which is why the voltage per tube is chosen to be as low as possible, considering economic factors, and röntgen radiation is preferred over gamma radiation. However, in certain cases where larger wall thicknesses are involved, scattered radiation can become so strong that higher energies or other radiation must be used to reduce it. Scattered radiation from the part and the environment reduces contrast and image quality, so it must be minimized using appropriate measures. The amount of scattered radiation produced increases with the thickness of the material. The best approach is to collimate the primary radiation as much as possible using masks and diaphragms to prevent scattered radiation from occurring. As the thickness of the material increases, the contrast and image quality decrease due to the need to increase the energy of the radiation for rational exposure times. Different irradiation geometries can also influence image quality, especially for flat defects, which give different contrasts depending on the direction of irradiation. The contrast of film and foils is primarily determined by blackening. The higher the blackening, the better the contrast. However, this requires sufficiently bright negatoscopes. The type and thickness of the film, as well as the film-foil contact, can also affect image quality, and control specifications should be closely followed. The type of film has negligible influence on contrast.

Unclear: Blurring of an exposure arrangement depends on geometric blurring, which can be minimized by reducing the geometric blur to a level that is essentially less than the internal blur. This can be achieved by using a small focal size, a large radiation source-part surface distance, and a small part surface-film and defect-film distance. Film slippage and other causes of blurring during exposure should also be avoided. The internal blur, or blurriness of the film-foil combination, is minimally affected by the type of film. Image quality improves with lower radiation energy and closer film-foil contact. It is crucial to ensure good film-foil contact to avoid blurriness.

Grain: The manufacturer assigns a given size of granulation to a film system class, and developing chemistry must be carefully matched to the film. The use of incorrect chemistry can lead to coarse grain or worsened film contrast, which may result in slippage into a lower film system class. Erroneous bath temperatures and developing times can also result in lower image quality. These issues may not always be noticeable when interpreting films, so it is important to carefully control darkroom work.

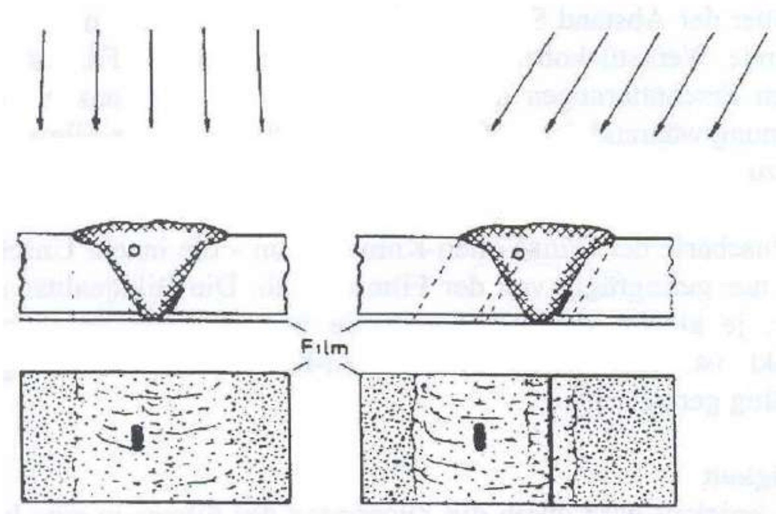


Figure 35

2.6.3.17. Image quality indicators according to EN ISO 19232-1

The concept of image quality and image quality indicators are important in film inspection. When a film appears free of defects, it can be difficult to determine if the object being inspected is defect-free or if the image quality is simply too low to detect any imperfections. To objectively assess image quality, test bodies have been developed and are visible on the film when irradiated with the object to be inspected. The resulting image property is called image quality, which is determined using standardized wire groups as defined in EN ISO 19232-1. These wire groups consist of several thin wires arranged parallel with stepped diameters, mounted in plastic pockets.

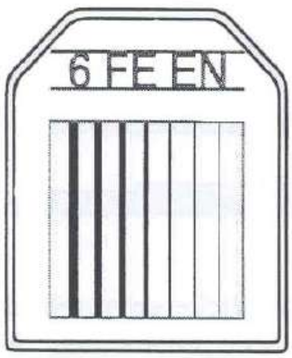


Figure 36

The correlation between the image quality index BZ and the diameter of the thinnest wire discernible on the X-ray can be calculated using the equation: BZ = 6 - 10 lg d. The BZ of the film is determined by the number of the thinnest wire discernible, with the lowest BZ being 1 and the highest BZ being 19. To streamline the process, groups of wires are selected based on penetrated thickness and assigned a BZ range, with 7 wires in each group. The wire materials in the groups should be the same as the object being tested, but due to practical limitations, only steel, aluminum, copper, and titanium wires have been standardized so far.

In other countries, Image Quality Indicators (IQI) are used, which consist of stepped plates or wedges with holes of different diameters drilled in them. EN ISO 19232-2 also standardizes this type of control body in addition to the wire group. The required image quality index depends on the penetrated wall thickness and can be determined using EN ISO 19232-1-3 or the corresponding exposure technique standard for welded or cast-in seam inspection.

To select the appropriate BPK image quality control body, the image quality index BZ must meet the minimum requirements based on the material being inspected. Two image quality classes are distinguished: image quality class A for control class A and image quality class B for control class B. The location of the BPK control body should be on the opposite side of the film facing the source, but can be applied on the film side in certain cases. The BPK should be tightly adhered to the test object, in a uniform wall thickness range, and represented in the middle of the clip.

The image quality index is determined by the base material and is considered perceptible if visible in a field of uniform blackness over a minimum continuous length of 10 mm. The BZ does not need to be confirmed on every radiograph of identical test objects, provided the exposure and processing technique remain the same.

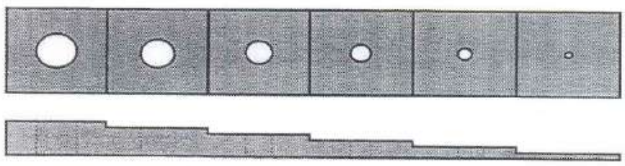


Figure 37

2.6.3.18. Marking films

To ensure clarity and accuracy in interpreting inspection findings and radiographs of welded seams and parts, various marking methods are utilized, including letters, numbers, lead symbols, and lead rollers. These markings are irradiated with the object to enable a correlation between the interpretable field of the film and the object. Other important information, such as stitch, order, and isometry no., may also be marked on the film for further correlation.

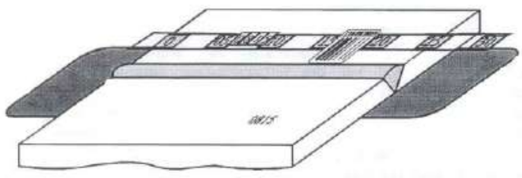


Figure 38

Different standards are in place for marking welded joints, and special measures are required for marking castings. To establish a clear reference system, "0" points can be marked on the part with an arrow indicating the direction of increase of the coordinate "0=>". For circular seams on pipes, the 12 o'clock positions and the direction of the clockwise coordinate increase relative to the direction of flow of the medium are stipulated. The ruler is shown with the symbols for the film welded seam, and it is laid out as it is normally read.

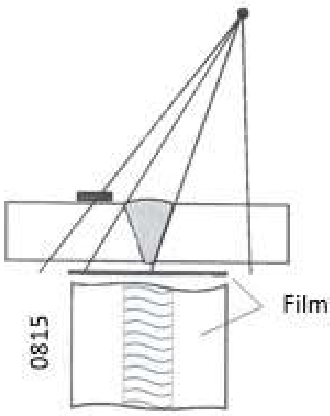


Figure 39

Lead symbols are placed on the piece and exposed with the piece if the placement of the scroll is impossible in corner seams and corner seam geometries. For non-perpendicular irradiation, the projection of the mark placed on the opposite side of the film is considered. The marking of ellipse welded seams is relatively easy to handle, where a lead letter, e.g. "A", is placed on the pipe and before the seam. If two exposures are required, a "B" is placed at the second exposure, which is offset by 90°. On circular welded seams with an outside diameter > 100 mm, container and boiler seams, and longitudinal and circular seams, a lead roller is usually used to mark the areas.

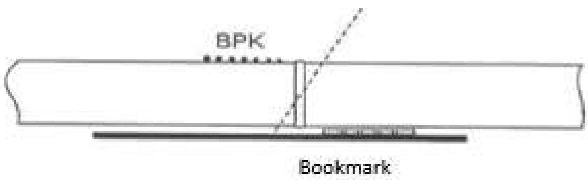


Figure 40

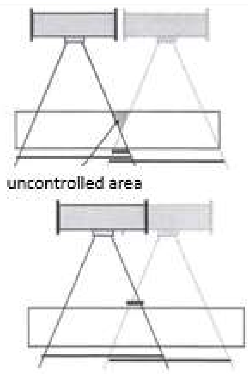


Figure 41

When marking molded parts, the area to be interpreted is marked with a minimum of two digits or lead letters, preferably four, in the corners of the area of interest if only one area of a casting is irradiated. If a part is to be irradiated 100%, it should be divided into a raster, and a list should be drawn up beforehand to account for differences in wall thickness and make unambiguous specifications on source position, exposure markings, object-source distance, film format, film type, number of exposures, source activity, exposure time, wall thickness, and image quality control body.

Overlap marking is done with care to ensure sufficient overlap in aligned films, especially for longer seams or cast areas with several partial exposures. The use of lead rollers is common for marking welded seams, and they can be used as an orientation for overlapping if they have sufficient undercut. These rules apply to welded seams and castings.

2.6.3.19. Checking the scattered radiation behind the film

To check for scattered radiation behind the film, a 12 mm high, 1.6 mm thick "B" symbol is placed behind the film in the marking. If the symbol is visible after exposure with the clip closed, it indicates insufficient rear protection against scattered radiation, and the clip may need to be rejected. Image quality control bodies should be chosen and placed according to wall thickness and located within the exposure mark. Beams should be arranged perpendicular to the seam on the base material, or wires may enter the seam if this is not possible.

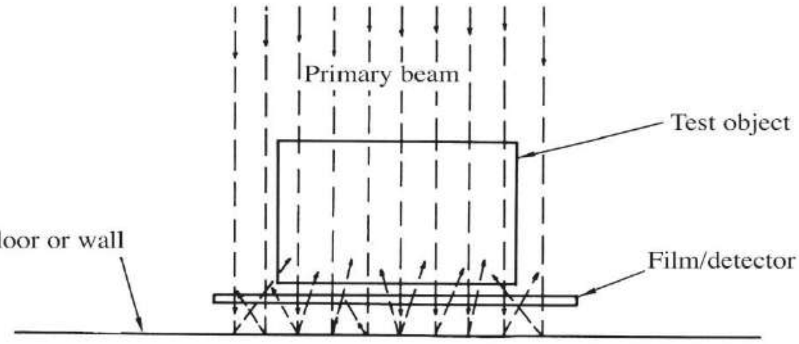


Figure 42

The choice of exposure arrangement, part geometry, geometrical blurring, wall thickness differences, irradiation position, focus, radiation source, control class A or B, film type, and prescribed film blackening can all influence the part-film marking and its interpretable range. A film layout plan can help correlate the object and the film at a later point in time without the part, making it easier for receptionists and clients to receive the films.

Limit values for appropriate control technique are provided in EN ISO 5579. The contrast of X-rays can be enhanced by reducing the energy to Röntgen radiation or using Röntgen installations instead of relatively easy-to-use gamma radiation. Increasing blackening can also increase contrast, so a minimum blackening is required corresponding to the control class. Scattered radiation, consisting of scattered radiation from the environment as well as scattered radiation generated in the part, can be reduced using collimators, diaphragms, and side, edge, and back coverings.

To protect the film against scattered radiation from the environment, the back of the film is provided with a lead coating. A zinc foil may also be placed between the film cassette and the lead back coating to filter out scattered radiation. A back cover is only considered rational if there are walls or other scattering bodies at less than about 2 - 3 metres behind the film. A lead letter fixed to the back of the film-film combination can be used to check whether scattered radiation has fallen back onto the film. The use of diaphragms and back coatings can only be insufficiently verified on the developed film, but the examiner should value a reduction of scattered radiation by back coverings.

Using a finer-grained film can improve image quality but requires prolonging the exposure time. The influence of good or bad contact between film and foil on the X-ray image was systematically analyzed in the 1980s and found to significantly increase internal blurring if films do not adhere tightly to the foil. A loss of image quality can also occur at a few tenths of a millimeter distance between film and film. Ready-made vacuum cassettes or vacuum film-foil combinations are recommended to minimize these issues.

2.6.3.20. Limitation of the test techniques

As you can see in the next's table, one limitation that occurred is the disponibility of the proper radiation source, that are not always available.

X-ray generators

Maximum voltage (kV)	Screens	Applications and Approximate Thickness Limits
50	None	Thin sections of most metals; moderate thickness of graphite and beryllium; small electronic components; wood, plastics, etc.
150	Lead foil	5-inch aluminum or equivalent. 1-inch steel or equivalent.
300	Lead foil	3-inch steel or equivalent.
400	Lead foil	3 1/2-inch steel or equivalent.
1000	Lead foil	5-inch steel or equivalent.
2000	Lead foil	8-inch steel or equivalent.
8 to 25 MeV	Lead foil	16-inch steel or equivalent.

Gamma-Ray Sources

Source	Applications and Approximate Practical Thickness Limits
Thulium 170	Plastics, wood, light alloys. 1 /2-inch steel or equivalent.
Iridium 192	11 /2- to 21 /2-inch steel or equivalent.
Cesium 137	1 to 31 /2-inch steel or equivalent.
Cobalt 60	21 /2- to 9-inch steel or equivalent.

Safety precautions can be hard to reach, sometimes in the safe zone all activities must be stopped.

The radiographer must have access to both sides of the test object.

For X-ray generators, there must be power supply on site, and there are problems regarding its dimensions and weight when positioning.

Planar discontinuities that are not parallel to the radiation beam are difficult to detect.

Radiography is an expensive testing method. Film radiography is time consuming.

Some surface discontinuities or shallow discontinuities may be difficult, if not impossible, to detect.

2.6.4 ISO 17636-1 according to X (röntgen) and gamma I and II radiation

2.6.4.1. Inspection of welded seams according to ISO 17636-1

This chapter begins by discussing some basic issues of radiographic inspection of welded seams to provide a better understanding before delving into the individual criteria of ISO 17636-1. Specifically, the discussion will focus on electrically or autogenously welded butt seams in sheets or pipes since radiographic inspection is applied to them in large volumes. However, it's worth noting that the possibilities of irradiation for other forms of seams, such as corner seams, are limited due to geometrical difficulties.

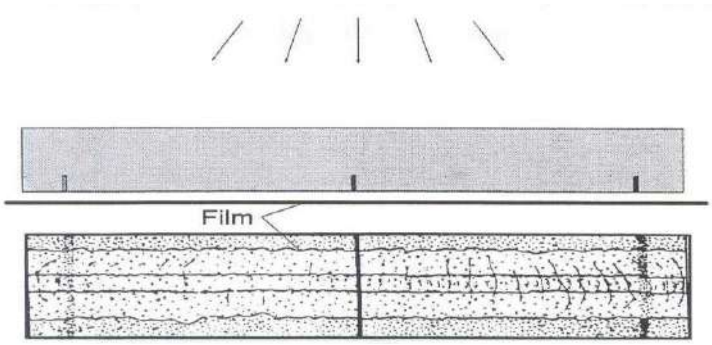


Figure 43

When it comes to irradiation geometry, perpendicular irradiation of the seam is the norm, and it is sufficient in most cases, especially in thin sheets. However, narrow, obliquely oriented defects, such as lack of melting on the flank or cracks, may only be noticeable with a very small irradiation angle tolerance. In such cases, additional irradiation should be carried out at an angle of about 15° - 30°, corresponding approximately to the angle of the flank or the melting line, from both sides.

As the direction of irradiation deviates more and more from the normal with increasing distance from the central beam in longitudinal section, it causes distortions. Therefore, the deviation should not become too great to detect transverse defects such as transverse cracks. Central exposures at circular stitches are the only possibility for distortion-free exposures.

According to experience, the root of the welded seam, usually the 1st layer, is the most difficult to make from a welding point of view. As a result, most defects occur in it. Therefore, if possible, the film should be placed on the root side for favorable conditions of representation (with pressure pipes, it's also necessary to note that the maximum stress occurs on the inner side). This technique of flat seam exposure is the norm.

In ISO 17636-1, the appropriate exposure arrangement and the performance at a given structuring of the part are presented to achieve an image quality appropriate to the control object. Given the sometimes-difficult detectability of certain welding defects, high image quality is generally required. In addition to the careful choice of exposure conditions (geometry, energy, etc.), this also requires the use of fine-grained, energy-dependent films with or without heavy metal foils (not salt foils). Of course, other considerations such as protection against scattered radiation (diaphragm, back cover), labeling, proof of image quality, etc., must also be taken into account.

2.6.4.2. Exposure arrangements according to ISO 17636-1and influence sizes

Exposure arrangements and their effects on welded seams according to ISO 17636-1 establishes the exposure arrangement for the irradiation of a flat welded seam, as shown in Figure 35.2, and provides guidelines for determining limit values using dimensions b, t, and f. While there are various irradiation possibilities for common circular welded seams, they may not always be applicable due to inaccessibility, unavailability of a suitable panoramic source, or the inability to meet the required minimum distance fin. In such cases, eccentric irradiation from the inside or outside may be performed, but this may cause distortions at the film ends and require several partial exposures on the circumference. The advantage of such methods is the position of the film near the root, but the use of Ir192 or Se75 gamma sources may lead to poorer contrast radiographs than X-ray radiographs, especially at small wall thicknesses.

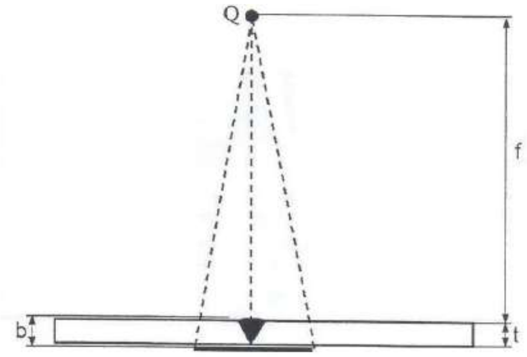


Figure 44

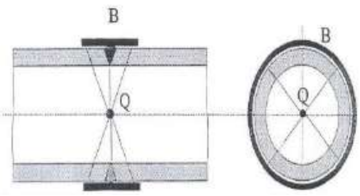


Figure 45

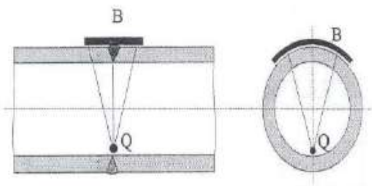


Figure 46

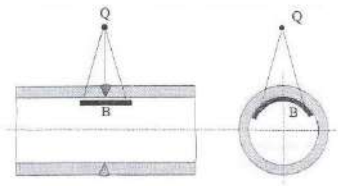


Figure 47

2.6.4.3. Double wall irradiation

Circular seams inaccessible to the interior require double-wall irradiation, where in addition to distortion and increases in wall thickness at the film ends, a loss of contrast must be calculated, which is caused by the fact that much more scattered radiation is produced through the second wall and the primary radiation is inevitably filtered and therefore hardened. This type of exposure should only be used when, for reasons of size or accessibility, single-wall irradiation is impossible. When working with the exposure arrangement a slightly tilted irradiation is usually done. The tilt should only determine that the blurred projection of the seam field close to the source does not overlap that of the field to be appreciated; and here it is useful to use a diaphragm, as suggested. Because only the welded seam area close to the film is to be assessed, ISO 17636-1 speaks of "plain image". Double-wall irradiation with gamma sources is often done with the collimated tip of the pull-out directly on the surface of the pipe near the seam, which is possible without any problems concerning the apparatus technique. This technique is the most common for inspecting welded seams on long-distance pipes of medium diameters. However, it should always be checked whether the prescribed distance fin is not somehow greater than the outside diameter. If this is the case a smaller source or a larger distance should be used. In practice often only 3 partial exposures are made of the circumference, offset by 120°, which is so unsatisfactory because the lateral fields cannot be fully appreciated. The required minimum number of N exposures per circumference must be determined according to ISO 17636-1.

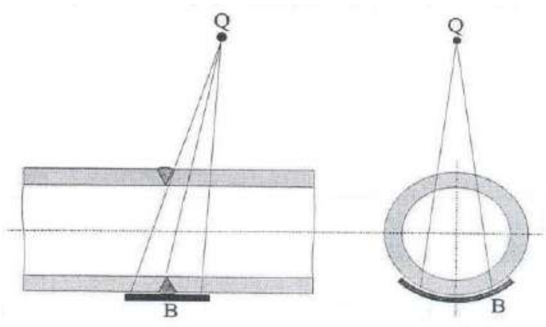


Figure 48

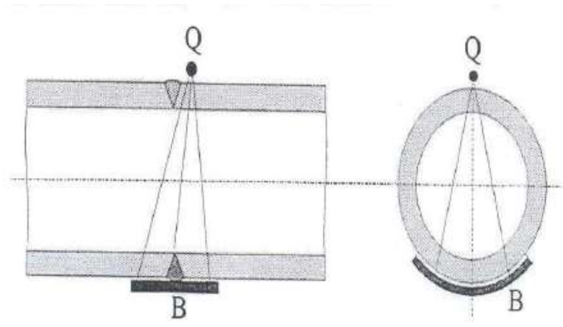


Figure 49

2.6.4.4. Irradiation of circular seams of small diameters

For welded seams of relatively small diameter (Da < 100 mm) the ellipse technique is applied.

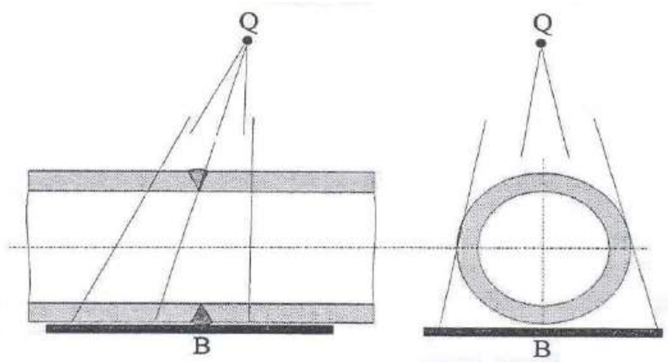


Figure 50

Because the ellipse technique radiates obliquely at such an angle that the entire seam is represented as an ellipse and therefore the lateral seam areas cannot be appreciated, 2 offset exposures at 90° resp. 3 at 60° must be made for the circumference coverage. While the film follows the curvature of the welded seam in all exposure arrangements discussed so far, in these two exposure techniques it lies flat under the seam. When determining the minimum distance in the distance b will be replaced by the outer diameter of the seam Da, because the top of the seam must also be represented.

2.6.4.5. Irradiation of corner joints

Based on their appearance (accessibility, thickness differences, large flank angles) corner joints are difficult to examine. Because of limited accessibility gamma radiographs are usually taken, often preferring a flank field.

Corner joints, lap joints, and other joints with considerable thickness differences often require special measures to be able to represent and interpret such wall thickness differences within the allowable blackness.

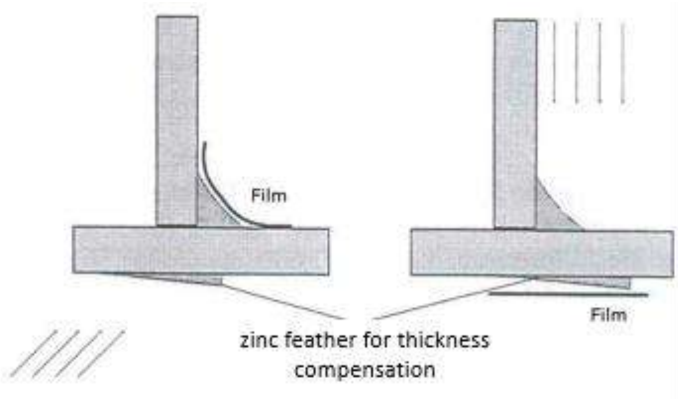


Figure 51

Other criteria: Certain weights, especially about the placement of sources and films, sometimes make joints unworkable (double curved), e.g., pipe junction joints, stub joints, and corner joints. Of course, here too, an attempt should be made to make irradiation through a simple wall, if possible, from the inside. To obtain a tight joint-film contact, relatively short pieces of the film should be laid side by side. Care must be taken to ensure sufficient overlap and complete marking, otherwise, film confusion can easily occur.

2.6.4.6. Inspection of welded joints according to ISO 17636-1

ISO 17636-1 applies to the use of penetrating radiation to inspect fusion welded joints of metallic materials, including copper (Cu), steel (Fe), titanium (Ti), aluminum (Al), and their alloys. This standard ensures that radiographic images have appropriate image quality and examination technique for the object being inspected. When quoted directly or as part of an inspection procedure, this standard must always be applied.

There are two classes of inspection distinguished in ISO 17636-1. Inspection class A is a general inspection technique, while control class B is a control technique of high control sensitivity. The choice of control class is a convention between the customer and the radiograph manufacturer based on the requirements of the control technique.

If a condition of control class B cannot be met, such as the choice of the radiation source or distance f, control class B is considered to have been met if the agreement increases the blackening to a minimum of D = 3.0. This possibility of agreement cannot be used if the special regulation according to point 6.6 of the standard (distance reduction) has been used.

The choice of exposure arrangement depends on the size, shape, range of examination, accessibility, and expected position of the defect of the object to be inspected. The welded seam should be irradiated as normally as possible (middle of the image), but in special cases where it is necessary to deviate from normal irradiation, this should be indicated in the inspection report.

There are special rules for certain display arrangements. Ellipse exposure shall not be applied if Da > 100 mm, the seam width Da / 4, or the nominal wall thickness is t > 8 mm. A minimum of 2 exposures offset by 90° is required for 100% control. If the ratio of wall thickness to outer diameter t / Da > 0.12, then a minimum of 3 exposures offset by 60° (resp. 120°) is required for a 100% check. If an ellipse exposure at diameters Da < 100 mm is no longer reasonable, normal irradiation of the standard may be applied. A minimum of 3 exposures offset by 60° (resp. 120°) is required for 100% control.

Table 5 - Control report

Object to control:			Control requirements:
Material:		Control class:	
Welding proces:			Imagine quality classi:
Seam shape:			Inspection volume:
Dimensions:			
Radiography marking			Exposure time calculation: B_{Diagr} = B_{korrig} = t_B =
Type of radiation source:			
Size of the warhead d (mm)			
Display arrangement according to figure			
Irradiation angle			
Maximum allowable tube voltage / Ir 192			
Film class / film type			
Sheets: type / thickness			
f_{min} (mm)	FFA (mm)		
U (kV)	I (mA)		
A (GBq)			
w_{Bel} (mm)	exposure time t_B (min)		
Exposure numbers N			
Care ICI	Position ICI		
D (requested/admitted)			
Image quality index (requested/admitted)			
Field of interpretation L (requested/admitted)			
Achieved control class	yes ☐ no ☐	Motivations:	
Image quality class achieved	yes ☐ no ☐		
Control volume achieved	yes ☐ no ☐		
Repeat exposure	yes ☐ no ☐		
City:	Date:		Controller:

The choice of radiation source is guided by the material, penetrated wall thickness w in the direction of the central beam, and control class. Röntgen radiation up to 500 keV is permissible for all wall thicknesses and materials, but above a certain wall thickness, it is no longer reasonable. In this case, the maximum allowable tube voltage indicated may not be exceeded.

If the minimum blackening results in seam overhangs and differences in wall thicknesses, exceeding the maximum permissible tube tension is allowed. For copper, nickel and its alloys, the increment shall be not more than 60 kV, for steel not more than 50 kV, for titanium and its alloys not more than 40 kV and for aluminium and its alloys not more than 30 kV.

The selection of exposure films and foils is guided by the limiting energy used (tube) or gamma source, penetrated wall thickness w, and control class. Registration of essential data from the object being controlled and controlled is necessary for the interpretation of the films. Control technique data such as the choice of source, exposure arrangement, films, etc. must be known to provide the possibility of a repeat exposure at a later point in time.

It is extremely important to have an unambiguous correlation between the object being controlled and the film. This must be ensured both by a clear film designation and by marking the controlled object, possibly also by a scale drawing or sketch.

The sample report at the end of the lecture summarizes the data that a penetrating radiation inspection report should contain. In cases of doubt about whether a detail is worth recording we should imagine the following situation: we are presented with a completely foreign finished film, and we must produce it under the same conditions. All the indications about the object to be controlled and checked, which are necessary for this, belong to a report. In addition, there must be columns for quality control on the finished film, in which the index and the image quality class are subsequently entered.

2.6.4.7. Typical imperfections for a welded joint

Welded joints may have two types of defects: volume and flat. Volume defects include foreign metal inclusions, voids, and pores, while flat defects consist of lack of fusion and cracks. The latter requires careful attention during inspection with penetrating radiation, as it is the most hazardous. The inspection technique is particularly challenging, as smaller notch widths for cracks and lack of melting require precise irradiation of the defect's extension direction, with a deviation of more than 5° making the defect imperceptible on the film.

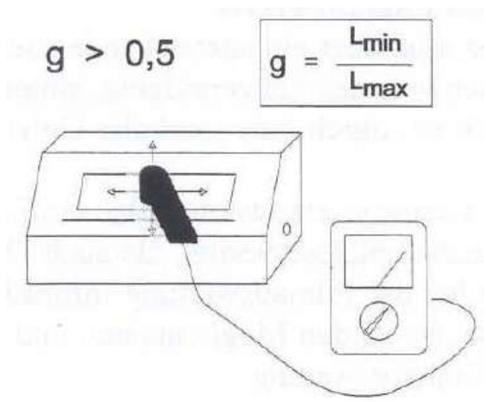


Figure 52

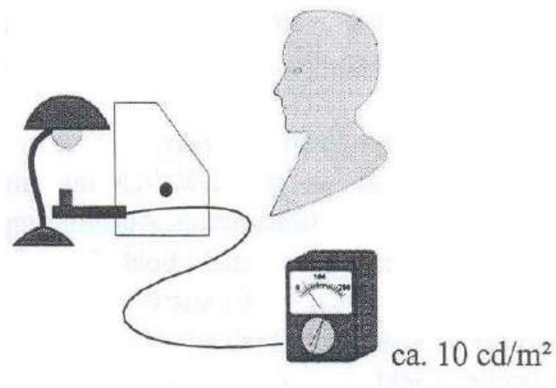


Figure 53

To provide interpretable films, the inspector of step 1 should verify the processed films' technical qualities of exposure and processing, rather than assessing defects. Before observing films, several marginal conditions should be considered, which are detailed in EN 25580. Negatoscopes for interpreting ready-processed films should meet specific requirements, such as having a minimum luminance to interpret films with higher blackness. The illumination of the illuminated surface must be uniform, with a permissible deviation towards the edge required by the uniformity factor g. The observer's glare can be avoided through the possibility of adjusting the brightness of the light and defined size of the illuminated surface.

The interpreter must have sufficient visual acuity, basic radiographic knowledge, and volume and procedure of film interpretation knowledge, as well as verify their visual acuity through annual analysis. Films should be viewed in a dry state to maintain their quality, and if viewed wet, must be handled with extra care to prevent damage to the emulsion layer. Films must be grasped at the edge or with gloves to prevent defects, and the heat exposure must be minimized to prevent deformation.

Before film observation, the marking, blackness, range of interpretation, and image quality must be checked, with the minimum blackening in the interpretable domain defined by ISO 17636-1. This range must be measured on the film and compared to the required control volume. The observer should use an image quality control body to determine the image quality index, the BPK position according to ISO 17636-1, and the additional designation F for the IQI placed on the film side.

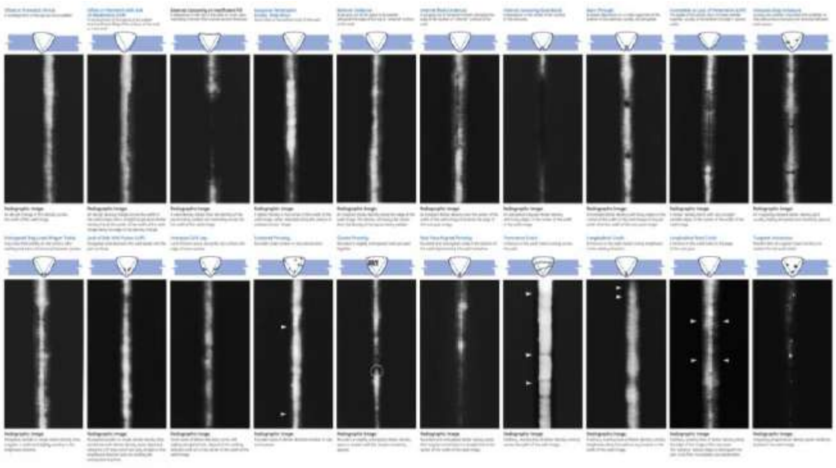


Figure 54

In order to proper interpret a radiographic image, the Welding Inspector must identify the defect, as in Figure 54.

After that, using ISO 10675-1 Non-destructive testing of welds - Acceptance levels for radiographic testing - Part 1: Steel, nickel, titanium and their alloys, or ISO 10675-2 Non-destructive testing of welds - Acceptance levels for radiographic testing - Part 2: Aluminium and its alloys, the indications, that occured in the radiographic image, must be evaluated according to the acceptance level.

For that, a verry good help can be found in: IIW. Reference radiographs for assessment of weld imperfections according to ISO 5817 publication.

2.7. Ultrasonic testing (UT)

2.7.1. Principles and application of UT

The basic principle of ultrasonic testing is the use of sound to inspect a material's thickness at different points. Ultrasonic thickness measurements can help inspectors find defects such as tiny cracks, gaps, corrosion, or other flaws in materials that are too minute to be seen by other NDT methods. It can also be used to find corrosion - if one area is thinner than another, that could be a sign that the area has been corroded, and may require maintenance. In addition to metal, an ultrasonic thickness test can be used to test plastics, composites, and ceramics. It can also be used to test concrete but the findings may not be as reliable.

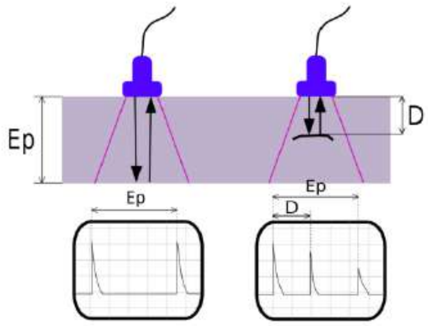


Figure 1 - Principle of ultrasonic testing. LEFT: A probe sends a sound wave into a test material. There are two indications, one from the initial pulse of the probe, and the second due to the back wall echo. RIGHT: A defect creates the third indication and simultaneously reduces the amplitude of the back wall indication. The depth of the defect is determined by the ratioD/Ep

Commonly tested using ultrasonic thickness measurement:

- Flare stacks
- Wind turbines
- Large storage tanks
- Her are the industries that commonly use ultrasonic testing as part of their inspection procedures:
- Aerospace
- Automotive
- Electronics & Battery
- Metals & Casting
- Oil and Gas
- Power Generation
- Railroad
- Inspectors use several different types of ultrasonic testing (ut) equipment.

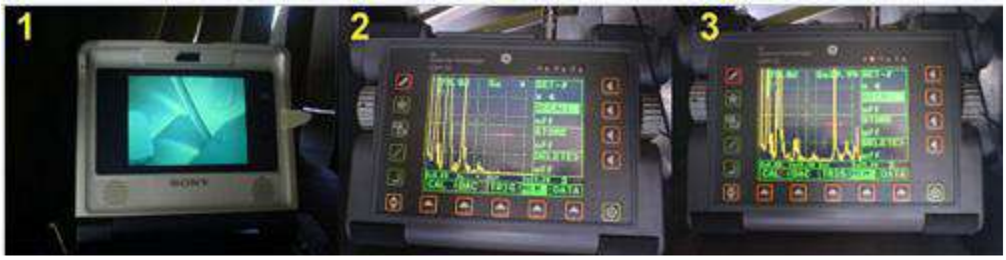


Figure 2 - An example of Ultrasonic Testing (UT) on blade roots of a V2500 IAEaircraft engine. Step 1: The UT probe is placed on the root of the blades to be inspected with the help of a special borescope tool (video probe). Step 2: Instrument settings are input. Step 3: The probe is scanned over the blade root. In this case, an indication (peak in the data) through the red line (or gate) indicates a good blade; an indication to the left of that range indicates a crack.

Some of this equipment is highly specialized, and may require the use of a technician trained in its use. Some companies hire third parties who are experts in the use of certain types of UT equipment and ultrasonic testing techniques, either to train internal team members on its use or to use the instruments and analyze their findings themselves. That being said, even the most sophisticated UT equipment is usually easy to care and use, and highly reliable.

Common types of ultrasonic equipment that inspectors use:

- Ultrasonic transducers and probes. Transducers are used in several types of ultrasonic thickness measurement, including weld testing and gauging thickness. Types include phased array, immersion, and contact transducers.
- Flaw detectors. Field-tested portable ultrasonic testing solutions for fast, accurate inspections for internal product integrity, searching for defects, cracks, and other discontinuities. Flaw detectors are portable, powerful, and sensitive, allowing inspectors to penetrate materials at a considerable depth.
- Thickness gauges. Ultrasonic thickness gauges are commonly used to inspect the thickness of various metals, including brass, steel, nickel, and lead, among others. Thickness gauges can be especially helpful for identifying corrosion.
- Automated UT systems. Automated ultrasonic thickness systems are systems that can be put in place and collect ultrasonic readings without an inspector physically present, allowing data collection that can be useful for the longevity of an asset even when someone isn't there. These systems are commonly used to monitor pipes in the Oil and Gas industry.

There are three main types of ultrasonic testing methods:

1. Through transmission

Through transmission employs two transducers, each placed on opposite sides of the material being tested. One of the transducers creates a pulse and the other receives it. If there is a disruption in the pulse, inspectors will know a defect is present in the path between the two transducers.

2. Pulse echo

Pulse echo is more sensitive than through transmission. It is used to identify defects by measuring the time it takes amplitude signals to travel between different points or surfaces in a material.

3. Resonance

Resonance is similar to pulse echo, except that with resonance testing the regularity of transmission can be changed. Resonance testing is primarily used when only one side of a material can be accessed.

2.7.1.1. What are Ultrasounds and how its work?

Ultrasonic examination is a widely used non-destructive testing technique that utilizes high-frequency sound waves to identify and locate flaws or irregularities within materials. To better understand the underlying principles of ultrasonic testing, it is important to first discuss what ultrasound waves are and how they function.

Ultrasound waves are sounds that are generated above the range of human hearing, typically above 20 kHz. The frequencies used for material control typically start at around 20 kHz for concrete control, but for ultrasonic testing, frequencies between 0.5 and 10 MHz are most commonly used.

When an ultrasound wave is generated, it creates pressure waves that propagate through matter, whether it is air, liquid, or solid. Ultrasound waves can travel through any medium that has molecules to move, but they travel faster in more elastic materials because the vibrations are passed on more quickly. For example, ultrasound travels faster in water or metal than it does in air because liquids and solids are more elastic than air.

One of the key properties of ultrasound waves is that they can be reflected off very small surfaces, such as defects inside materials. This property is what makes ultrasound useful for non-destructive testing of materials. By sending ultrasound waves into a material and measuring the reflected waves, it is possible to detect and locate flaws or irregularities within the material.

The speed of the ultrasound wave is dependent on the type of wave and the material in which it is propagating. When waves propagate, there is energy transport rather than mass transport. Waves traveling in solid materials are always attenuated, meaning that the energy of the wave is gradually reduced, leading to a decrease in amplitude. This attenuation is an important factor to consider when performing ultrasonic testing, as it can impact the accuracy and reliability of the results obtained.

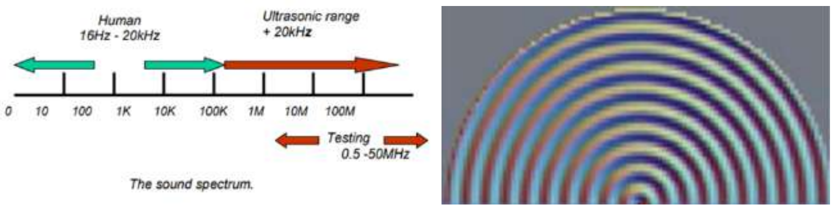


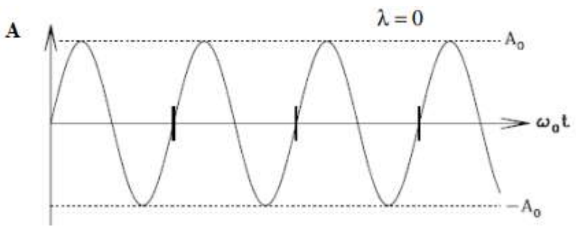
Figure 3 - Represents sound spectrum and sound wave

Ultrasonic testing utilizes high-frequency sound waves above the range of human hearing to detect and locate flaws or irregularities within materials. The principles of ultrasonic examination rely on the ability of ultrasound waves to propagate through matter and reflect off small surfaces, as well as the speed and attenuation of the waves. By understanding these principles, it is possible to perform effective and reliable ultrasonic testing for a variety of materials and applications. An UT report is a document that summarizes the results of an ultrasonic inspection. It typically includes information such as the type of inspection performed, the equipment used, the test results, and any conclusions or recommendations based on the results. Following enforced standards is important to ensure that the report contains all necessary information and is accepted by clients or regulatory agencies. One of the advantages of ultrasonic testing is that it can be performed on a wide range of materials, including metals, plastics, composites, and ceramics. It is also a non-destructive testing method, which means it does not damage the material being inspected. However, there are also some disadvantages to ultrasonic testing, such as the need for direct contact between the transducer and the material, limited penetration depth in some materials, and difficulties in inspecting complex shapes.

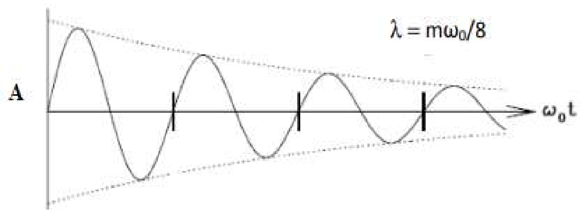
Ultrasonic testing can be performed in different modes, including pulse-echo, through-transmission, and phased array. Pulse-echo is the most common mode used in industrial applications, where the same transducer is used to both transmit and receive the ultrasound waves. Through-transmission mode uses two transducers on opposite sides of the material to transmit and receive the ultrasound waves. Phased array mode uses multiple transducers that can be electronically steered to create and focus beams of ultrasound in specific directions.

Ultrasound waves are generated by a transducer which converts electrical energy into mechanical vibrations. These vibrations are then transmitted into the material being inspected. As the ultrasound waves travel through the material, they are reflected back to the transducer if they encounter a boundary between materials or a defect within the material. The reflected waves are then converted back into an electrical signal which can be analysed to determine the properties of the material being inspected. The analysis of the signal can be used to detect defects such as cracks, voids, and inclusions, as well as measure properties such as material thickness, sound velocity, and attenuation.

Ultrasonic waves are based on oscillations, which represent a periodic process that gets repeated at regular intervals. These oscillations are described in detail using various notions. Firstly, the amplitude, represented by the abbreviation A, is the maximum amount of displacement of a particle on the medium from its rest position. Secondly, the oscillation duration, represented by the abbreviation T, is the regular time interval required for a complete oscillation. The amplitude of an oscillation determines the energy carried by the wave. The larger the amplitude, the greater the energy. The frequency, represented by the abbreviation f, is the number of oscillations per second. Frequency is related to the pitch of a sound. Higher frequencies correspond to higher pitched sounds, while lower frequencies correspond to lower pitched sounds. The wavelength, represented by the abbreviation lambda (λ), is the distance between two similar points in the same oscillation state. Wavelength is related to the distance between successive peaks or troughs of a wave. It is commonly represented by the Greek letter lambda (λ). The wavefront represents the front line of a propagating wave train whose points have the same oscillation state. Wavefronts can be used to visualize the propagation of waves. They are like the crests of ocean waves or the fronts of ripples on a pond. The propagation velocity, represented by the abbreviation c, is the velocity at which the wavefront propagates and depends on the elastic properties and density of the medium in which the wave propagates. The propagation velocity of a wave is dependent on the medium through which it is traveling. In a given medium, the velocity of a wave is determined by the density and elastic modulus of the material.



Non-attenuated osculation: constant amplitude



Attenuated oscillation: decreasing amplitude

Figure 4 - Oscillation: non-attenuated and attenuated

The unit of measurement of frequency is the hertz, abbreviated as Hz, which is equivalent to one oscillation per second. There is a simple relationship between the frequency f and the oscillation time T: f = 1/T. For all waves, irrespective of the wave type, a relationship exists between the wavelength λ, propagation velocity c, and frequency f, which is represented as:

$$\lambda = c/f$$

This relationship indicates that as the frequency increases, the wavelength decreases, and vice versa. It is also important to note that the propagation of waves in solid materials is always attenuated, which results in the reduction of energy and a decrease in amplitude.

Additionally, the relationship between frequency, wavelength, and propagation velocity is often expressed as the wave equation:

$$c = \lambda f$$

- where c is the propagation velocity, λ is the wavelength, and f is the frequency. This equation can be used to calculate any one of these values if the other two are known.

2.7.1.2. Types of waves

Ultrasound waves can be categorized into four types based on their direction of oscillation and propagation.

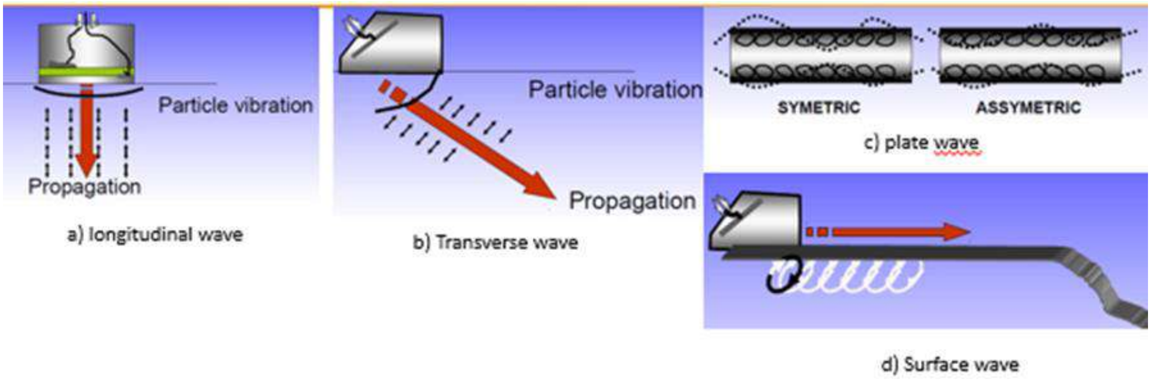


Figure 5 - Types of waves

The first type is longitudinal (compression) waves, in which the direction of oscillation is the same as the direction of propagation. These waves can travel through gaseous, liquid, and solid media. However, in solids, other types of waves may also occur in addition to longitudinal waves.

The second type is transverse (shear) waves, in which the direction of oscillation is perpendicular to the direction of propagation. These waves can only propagate through solid media. An example of transverse wave propagation can be seen in elastically coupled spring pendulums where the pendulums oscillate in the vertical direction and waves propagate in the horizontal direction. The (shear) waves maybe also:

- Shear-horizontal (SH) waves: these waves have a horizontal oscillation and a shear component, and they are useful for inspecting certain types of defects in welded joints and composites.

-Shear-vertical (SV) waves: these waves have a vertical oscillation and a shear component, and they are useful for inspecting the near-surface regions of metals.

The third type is plate (Lamb) waves, which are symmetric or asymmetric waves that propagate in thin plate materials when the plate thickness is approximately the same as the wavelength. These waves are similar to plate waves, but they can propagate in thicker plates. Lamb waves are important for inspecting plates, pipes, and other structures where there is a large surface area. They are commonly used for corrosion and crack detection.

The fourth type is surface (Rayleigh) waves, which have an elliptical particle motion and travel across the surface of a material. The depth of penetration of these waves is approximately equal to one wavelength.

In ultrasonic testing, the most common types of waves used are longitudinal (compression) waves and transverse (shear) waves. Longitudinal waves are commonly used for material inspection while transverse waves are used for both material and weld inspection. The velocity of these waves is usually known and assumed to be constant in ultrasonic inspection. The choice of wave type depends on the material being inspected and the type of defect being searched for. Longitudinal waves are the most commonly used in ultrasonic testing, as they can travel through both solid and liquid materials and can detect a wide range of defects, including voids, cracks, and inclusions. Transverse waves are used for specific applications, such as weld inspections, where they can detect defects that might not be visible to longitudinal waves.

In ultrasonic inspection, the velocity of the wave is an important parameter that is usually known and assumed to be constant. The velocity depends on the properties of the material being inspected, such as its density, elasticity, and temperature. The velocity of the wave can be used to determine the thickness of the material, the location of defects, and other properties. Overall, the choice of ultrasonic wave type and the understanding of wave velocity are important factors in the successful application of ultrasonic testing in industry.

2.7.1.3. Ultrasound velocities

Ultrasound velocities vary depending on the type of vibration and the material in which the wave is traveling. The speed of the wave in a material depends on the density and elasticity of the material. Materials with higher density and elasticity tend to have higher velocities of ultrasound waves, which allows the waves to travel through the material faster.

Material	Compression velocity, m/sec	Shear velocity, m/sec
Air	332	NA
Water	1480	NA
Steel	5920	3250
Aluminium	6320	3130
Perspex	2730	1430
Copper	4700	2260
Brass	4430	2120

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

V_L = Longitudinal bulk wave velocity
E = Young's modulus of elasticity
μ = Poisson ratio
ρ = Material density

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

V_s = Shear wave velocity
E = Young's modulus of elasticity
μ = Poisson ratio
ρ = Material density
G = Shear modulus

Ultrasound waves can reflect off surfaces, which makes them useful for locating defects or abnormalities in materials or estimating the size of defects inside materials. By knowing the speed of the ultrasound wave and the time it takes for the wave to travel to the defect and back, the distance to the defect can be calculated. The amount of reflected energy can be used to estimate the size of the defect or irregularity. By analysing the time between the transmitted and reflected waves, we can also calculate the distance at which the reflection occurred. In ultrasonic testing, the time it takes for a wave to travel through a material and reflect back is measured to determine the thickness of the material. The difference between the time of transmission and reflection is used to calculate the distance the wave has travelled, and by knowing the velocity of the wave in the material, the thickness of the material can be calculated. The velocity of ultrasound waves depends on the type of vibration and the material through which the wave is traveling. In general, the speed of ultrasound is higher in more elastic materials, such as metals and liquids, and lower in less elastic materials, such as gases. The amount of energy reflected by a defect depends on the size and nature of the defect, as well as the frequency of the ultrasound wave used. A large defect or one with a high degree of reflectivity will produce a stronger reflection than a smaller or less reflective defect. Overall, ultrasound is a valuable tool for non-destructive testing of materials and can provide useful information about the properties and integrity of a material.

2.7.1.4. Generating Ultrasound

Ultrasound is generated using the piezo-electric effect, which converts mechanical energy into electrical energy. This effect is reversible, meaning that an electrical voltage can be converted into mechanical energy or sound, which is the reverse piezo-electric effect.

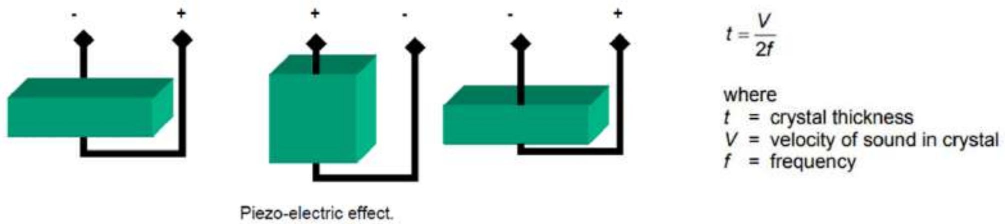


Figure 6 - Piezo-electric effect

Piezoelectric elements like quartz, barium titanate, and lead zirconate titanate can be used to generate ultrasound waves. When these elements are deformed, an electrical voltage occurs between the outer metal electrodes, which is the direct piezoelectric effect. On the other hand, if an electrical voltage is applied to the electrodes, the element is deformed, converting electrical energy into mechanical energy or sound, which is the reverse piezoelectric effect. In ultrasonic testing, the reverse piezoelectric effect is used for transmission, while the direct piezoelectric effect is used for reception.

The frequency of the generated ultrasonic oscillation depends on the thickness of the piezoelectric element. Each material has a known speed of the ultrasonic wave. By using the formula $\lambda = c/f$, where c is the speed of the wave and f is the frequency of the wave, the wavelength can be calculated for a specific frequency. Different materials have different ultrasonic wave speeds, which affect the wavelength of the wave at a given frequency.

In non-destructive testing (NDT) practice, it is known that the minimum detectable defect dimension is usually above 0.5 λ, depending on the orientation of the defect. This means that the size of the defect that can be detected using ultrasound depends on the wavelength of the wave.

The sound field is the region in which sound waves propagate from a vibrating source. The shape of the sound field is influenced by the size of the oscillator D and the constructive frequency f of the sound waves. When the vibration source is not a point but rather a plane, the sound field takes on a cone-like (conical) shape that is similar to a flashlight beam. The size and shape of the sound field are important considerations in non-destructive testing as they determine the area of the material that can be inspected and the accuracy of the measurements obtained.

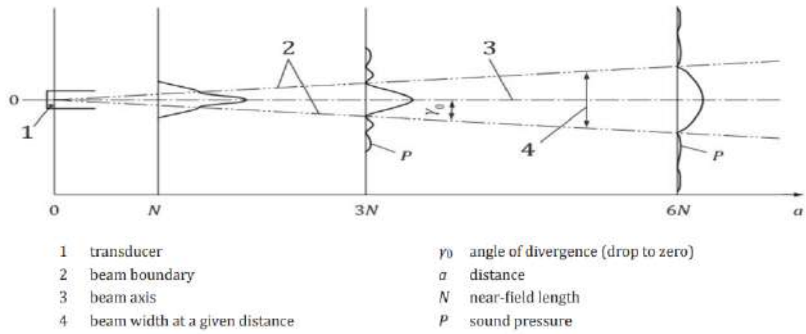


Figure 7 - Sound field

When discussing the sound field, there are several important characteristics that can be defined. One of these is the near zone, also known as the Fresnel zone or near field. This is the region immediately surrounding the transducer, where the sound waves are still converging and haven't fully spread out yet. In this zone, signals from a reflector may not accurately represent its size, and small reflectors may be missed altogether. Within this zone, signals from a reflector may not have an accurate relation to the size of the reflector, and small reflectors may even be missed. The far zone, also known as the Fraunhofer zone or far field, on the other hand, is where sound pulses follow the inverse square law, which means that they spread out as they move away from the crystal and their intensity will decay exponentially. In this zone, the beam width is relatively narrow and the size of the reflector can be accurately determined.

Another characteristic of the sound field is the angle of divergence. This angle is defined as the angle within the far-field between the beam axis and the beam boundary, and it can be measured as a -6dB or -20dB drop. A narrower angle of divergence means that the beam is more focused, while a wider angle means that the beam is more spread out. This angle is influenced by factors such as the size and shape of the transducer, the frequency of the sound waves, and the distance from the transducer.

2.7.1.5. Ultrasonic Transducers

The size of the transducer, specifically its diameter (D) and its frequency (f), are two major factors that can affect the shape and length of the sound field. The shape or angle of the sound field and the length of the near zone can be calculated based on these factors. Generally, the greater the diameter of the crystal in the transducer, the larger the near zone will be. The near zone is the region closest to the transducer where the sound waves are still in a focused state. Similarly, a higher frequency of the crystal can result in a larger near zone. Furthermore, larger crystal diameters tend to result in less spreading of sound waves, while higher crystal frequencies tend to result in less spreading of sound waves as well. These conclusions can be helpful in understanding the behaviour of sound fields and can aid in designing and optimizing transducers for specific applications.

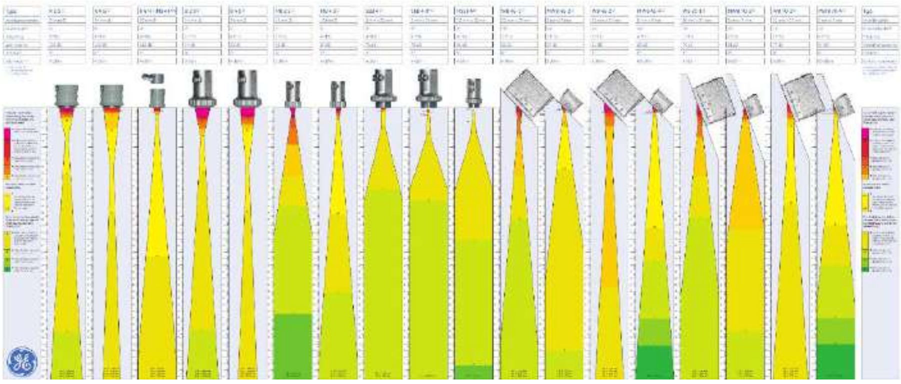


Figure 8 - Types of the transducer

The angle of the sound field is also influenced by the size and frequency of the crystal. Larger crystals produce a narrower angle of the sound field, while smaller crystals produce a wider angle. Higher frequencies also produce a narrower angle of the sound field compared to lower frequencies. Finally, the diameter and frequency of the crystal also affect the spread of the sound waves. Larger crystals cause less spreading of the waves in the far zone, while smaller crystals result in more spreading. Higher frequencies also cause less spreading compared to lower frequencies.

Ultrasonic Transducers, Straight Beam

Ultrasonic Transducers are devices that convert electrical energy into sound waves and vice versa. Ultrasonic transducers are devices that convert electrical energy into acoustic energy in the form of sound waves, which can then be used to detect flaws or changes in the material being tested. One type of ultrasonic transducer is the Straight Beam Contact Transducer, which produces longitudinal waves that are normal at the contact surface. These transducers are typically used for general purpose inspections of larger parts with simple geometry such as forgings, billets, plates, bars, square profiles, containers, machine components, and shells.

Figure 9 - Straight Beam Contact Transducer

Additionally, Straight Beam Contact Transducers can be used for inspection at high temperatures with a delay line. They are commonly used in various industries such as aerospace, automotive, and manufacturing to detect defects, measure thickness, and monitor material properties. Overall, straight beam contact transducers are a versatile tool for non-destructive testing of various materials and components.

Ultrasonic Transducers, Straight-Beam Dual Element TR

Ultrasonic transducers are devices that are used to generate and detect ultrasonic waves. The straight beam dual element TR transducer is a type of ultrasonic transducer that produces longitudinal waves normal at the contact surface. It is composed of two independent transducers that are enclosed in the same casing. One of the transducers transmits the ultrasound (T), while the other receives it (R).

Figure 10 - Transducers, Straight-Beam Dual Element TR

The straight beam dual element TR transducer is used in various applications, such as measuring remaining wall thickness, corrosion, and erosion. It is also used for near surface flaw detection, examining small parts like screws, bolts, and pins, cladding and weld overlay, bond testing, railroad wheels, and examination of coarse grain materials. In addition, this type of transducer is suitable for detecting core flaws in shafts, bars, and billets. Its design and functionality make it an effective tool for non-destructive testing and evaluation in various industries, including manufacturing, construction, and transportation.

Ultrasonic Transducers, Angle Beam Transducers

Angle Beam Contact Transducers are ultrasonic transducers that produce transversal waves. They are composed of a piezo-electric crystal that is mounted on a Perspex wedge at an angle, which is calculated to generate a shear (transverse) wave in the test material at a known angle. Angle beam contact transducers are primarily used for general weld inspection, smaller objects, and thinner sections. They are also used for testing tubes, pipes, pressure vessels, containers, pumps, valve housings, turbine blades, shafts, and wheel rims.

Figure 11 - Angle Beam Contact Transducers

The advantage of angle beam contact transducers is that they allow for the detection of defects that are not visible on the surface of the material being tested. They are also able to inspect areas that are difficult to access, such as the interior of pipes and vessels. The angle of the wedge can be adjusted to achieve different angles of incidence and to optimize the detection of specific types of defects.

These transducers are commonly used for general weld inspection, smaller objects, thinner sections, tubes, pipes, pressure vessels, containers, pumps, valve housings, turbine blades, shafts, and wheel rims.

2.7.1.6. Behaviour of ultrasonic waves at normal incidence on a boundary surface:

The piezoelectric elements produce vibrations that are transmitted to the tested material through a thin liquid called a „coupling medium". Common couplants mediums used in ultrasonic testing include water, oil, grease, and glycerine. The choice of the coupling medium depends on the specific application, the materials being tested, and other factors.

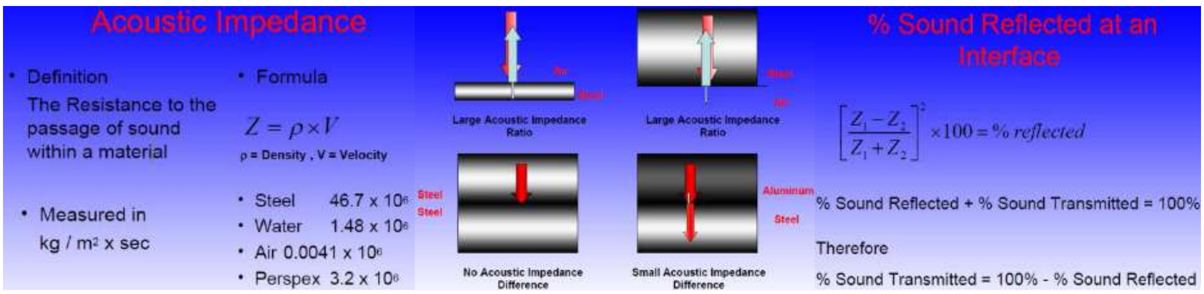


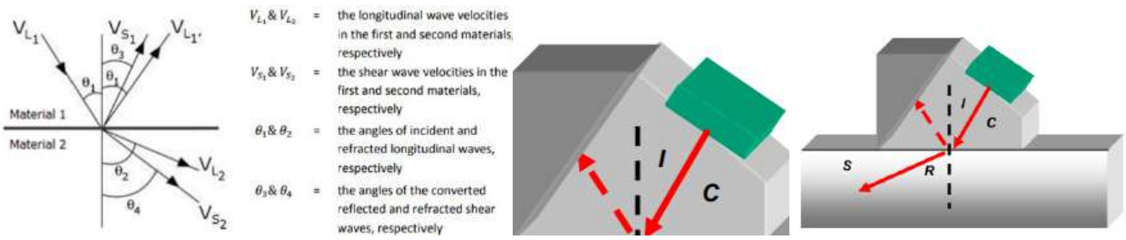
Figure 12 - Represents a ultrasound waves encounter a boundary surface

When the ultrasound waves encounter a boundary surface in the tested material, reflection and transmission occur. The percentage of energy transmitted depends on the difference in acoustic impedance between the two materials. If there is a large difference in acoustic impedance, the reflected component becomes larger than the transmitted one, and it's almost impossible to transfer ultrasound energy in steel through air.

At the interface between Perspex and water, approximately 85% of the energy is transmitted, and at the interface between water and steel, only about 12% of the energy is transmitted in either direction. Similarly, at the interface between water and Perspex, around 85% of the energy is transmitted. Therefore, adding up all these percentage reductions, only about 2% of the produced energy can be used as a signal received by the piezoelectric elements. It's important to note that these values don't take into account the fact that the wave is always attenuated, and the quantity of energy transmitted and received is reduced due to improper coupling between the transducer and the examined material. Combining all the percentage reductions, we can see that only about 2% of the produced energy can be used as a signal received by the piezoelectric elements. However, these values do not take into account the attenuation of the ultrasonic wave or the loss of energy due to improper coupling between the transducer and the examined material.

2.7.1.7. Angle Beam Transducers, Snell Law

When a sound beam is directed towards an interface between two materials at an angle other than normal, two phenomena occur: reflection and refraction. The reflection happens when the sound wave is bounced back at the same angle it hit the interface, while the refraction involves a change in direction and speed of the wave as it enters the second material. The degree of refraction depends on the angle of incidence and the difference in acoustic impedance between the two materials. The Snell's Law formula can be used to calculate the angles of the refracted waves based on the angle of incidence and the acoustic properties of the two materials. This principle forms the basis for the construction of angle beam transducers.



$$\frac{\sin\theta_1}{V_{L_1}} = \frac{\sin\theta_2}{V_{L_2}} = \frac{\sin\theta_3}{V_{S_1}} = \frac{\sin\theta_4}{V_{S_2}}$$

Figure 13 - The Snell's Law formula and principle forms the basis for the construction of angle beam transducers

The piezoelectric crystal in an angle beam transducer generates a compressional wave that is transmitted into the Perspex wedge. When the compressional wave hits the bottom surface of the wedge, the energy is reflected away from the interface and back into the Perspex, where it is dampened inside of the transducers. If there is a coupling medium and the probe is placed on the test material, a part of the generated sound energy passes into the test material and generates a shear wave.

Angular beam transducers are used in cases where conventional straight beam probes fail to provide accurate results, especially for weld inspection and flaw detection such as cracks or inclusions. They are particularly beneficial for scanning for defects present in the welding process or for inspecting erosion and corrosion of metal pipes and tanks. In addition, the beam angle can be adjusted to increase the accuracy of defect detection in a particular material. When the angle beam transducer is attached to the test material by a coupling medium, such as oil or water, some of the sound energy produced penetrates the test material, producing a shear wave. This wave helps detect defects and flaws, such as cracks or inclusions, by studying the reflections and echoes generated by the wave as it passes through the material.

Angle Beam Transducers, critical angles

The possibility of obtaining shear waves in steel with angles ranging from 30 to 75 degrees by modifying the angle and material of the Perspex wedge is representing in the picture below. However, it is important to note that angles less than 30 degrees produce two refracted components, which makes the transducer unsuitable for use. Conversely, larger angles lead to the refracted shear wave becoming a surface wave.

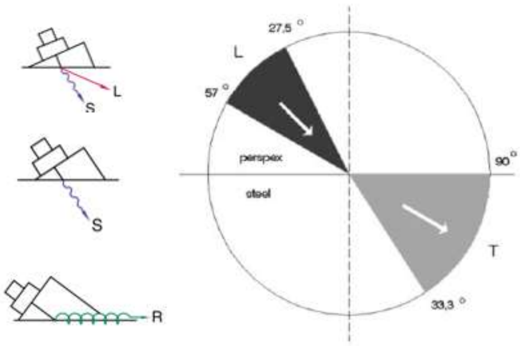


Figure 14 - Angle Beam Transducers, critical angles

In non-destructive testing (NDT) practice, the usual angles for constructive shear waves are 35, 45, 60, 70, 80 and 90 degrees (surface waves). The specific angle chosen for a particular application depends on the probable orientation of the flaw. It is important to consider that the maximum reflection of the wave occurs when the angle between the beam and the flaw is 90 degrees. This means that the transducer's construction angle must be optimized for the specific application such as weld inspection and corrosion or erosion examination of metal pipes and tanks, to ensure accurate and reliable flaw detection.

2.7.1.8. Attenuation

Ultrasound waves are subject to attenuation, meaning that they decrease in intensity as they propagate through a medium. There are three main causes of attenuation: diffraction, scattering, and absorption, assuming there are no significant reflections. The degree of attenuation in a material is a critical factor in determining the appropriate transducer for a particular application, and it is measured in dB/m.

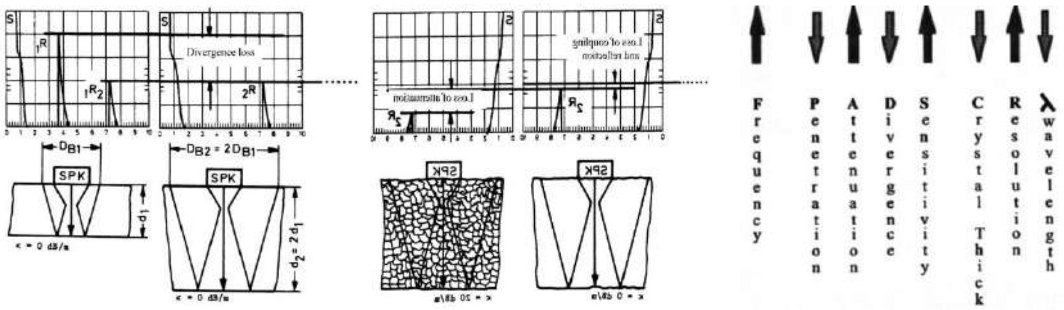


Figure 15 - Ultrasound waves – attenuation

Diffraction occurs due to beam divergence and is a property of a specific transducer. The angle of divergence determines the degree of diffraction and is a critical parameter to consider when selecting a transducer. Scattering occurs when ultrasound waves reflect or diffract on grain boundaries. This phenomenon depends on the ratio of grain size over wavelength (λ), and the larger the grain size, the more significant the problem. The higher the frequency of the probe (smaller wavelength λ), the worse the scattering problem becomes. Absorption occurs when ultrasound energy is converted into other forms of energy, such as heat due to friction. As the frequency of the ultrasound increases, absorption increases due to more particle vibration, which leads to increased sensitivity to small reflectors. Both scattering and absorption components also increase with higher frequencies. To minimize the impact of ultrasonic attenuation, a lower frequency with a longer wavelength should be selected. However, the resolving power of defects decreases with increasing wavelength, meaning that a higher frequency must be chosen to detect small defects. Therefore, selecting the most favourable frequency always involves a trade-off between the highest possible defect resolution and minimal ultrasonic attenuation. Due to the small electrical signals received from the transducer after detecting an ultrasonic reflection, amplification is necessary to make the signals useful.

2.7.1.9. Ultrasonic Instrument. Block diagram

An ultrasonic A scan equipment is used to generate and receive ultrasonic pulses, which are used for non-destructive testing of materials. The equipment can be either analog or digital and consists of several components. This equipement consists of a pulse generator that produces control pulses at a definite repetition rate ranging from 50 to 1000 Hz.

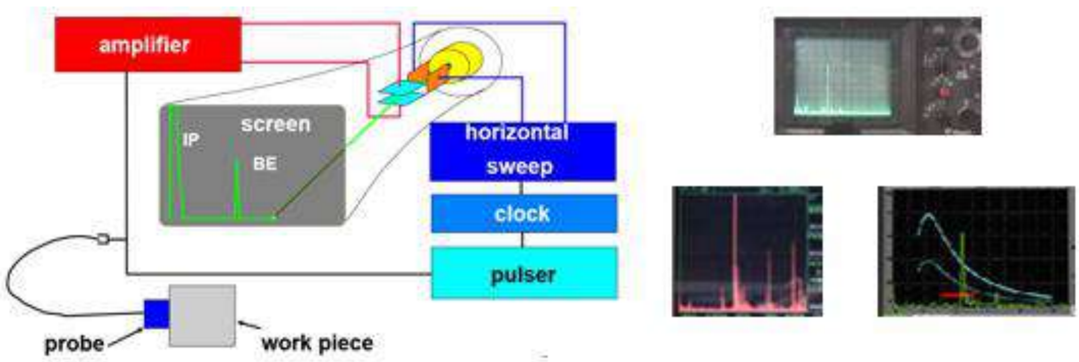


Figure 16 - An ultrasonic A scan equipment

The transmitter takes these control pulses and forms emission pulses with amplitude heights ranging from 50 to 300 V. These emission pulses are fed via a control cable to the transducer, which then converts them into ultrasonic pulses. The mode switch determines whether one transducer is used for both transmitting and receiving ultrasonic signals or if two separate electrical and acoustic systems are used for transmission and reception. If only one transducer is used, the mode switch is closed. If two separate systems are used, the mode switch opens. The received ultrasonic signals are converted back to electrical signals by the transducer and then formed and amplified by the receive amplifier for representation. The amplification and with it the height of the represented indications can be adjusted in known steps of 0.2 to 12 dB, up to approximately 110 dB. This amplification is done on a logarithmic scale. Finally, the horizontal deflection, or time base, allows for the localization of received signals based on measured time and the known speed of propagation. This is done on a linear scale. Together, these components make up an ultrasonic A scan equipment, which can be used for a variety of non-destructive testing applications.

2.7.1.10. Signal amplification, logarithmic scale

Ultrasound intensity, like sound intensity, can be measured using the Bell or its subunit, the decibel. Since the actual energy being transmitted by an ultrasound probe is unknown, sound intensities can only be compared and expressed as a ratio (e.g. twice as much, ten times as much).

$$dB = 20 \log_{10} \frac{H1}{H2}$$

Where H1 and H2 are the respective signal heights.

Table of approximate dB drops:

dB	H2	Drop	H1:H2 ratio
20	10%	90%	10:1
14	20%	80%	5:1
12	25%	75%	4:1
10	33%	67%	3:1
6	50%	50%	2:1
2	80%	20%	5:4

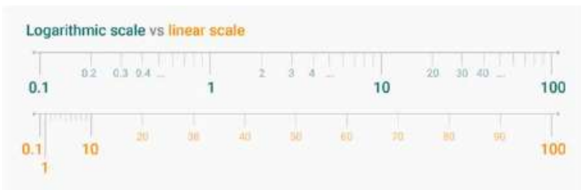


Figure 17 - The logarithmic scale

A change in sound intensity can be measured in dB by comparing signal heights on a calibrated instrument. The change in dB is given by a formula, which can be transposed to determine the ratio of signal heights when the dB difference is known. The gain controls on a conventional ultrasonic flaw detector are calibrated in decibels, meaning that reducing the ultrasound intensity by 6dB will cause any signal on the screen to drop to half its original height. Similarly, reducing or increasing the intensity by 20dB will cause the signal to reduce to a tenth or increase by ten times its original height, respectively.

The logarithmic scale is used in ultrasound intensity measurements because it simplifies calculations involving amplification and attenuation factors between 1 and 10,000. The logarithmic scale also offers the advantage of being able to plot both very small and very large values clearly, thanks to the loss of the zero point and equidistant scale divisions.

2.7.2. Ultrasonic inspection techniques.

The reflected-pulse technique is a commonly used method for manual ultrasonic inspection due to its advantages over the transmission technique. One of these advantages is the direct detection of imperfections, which allows for the measurement of the amount of reflected sound energy. The amount of reflected energy depends on factors such as the size, shape, and orientation of the imperfection, as well as the surface characteristics of the material being inspected.

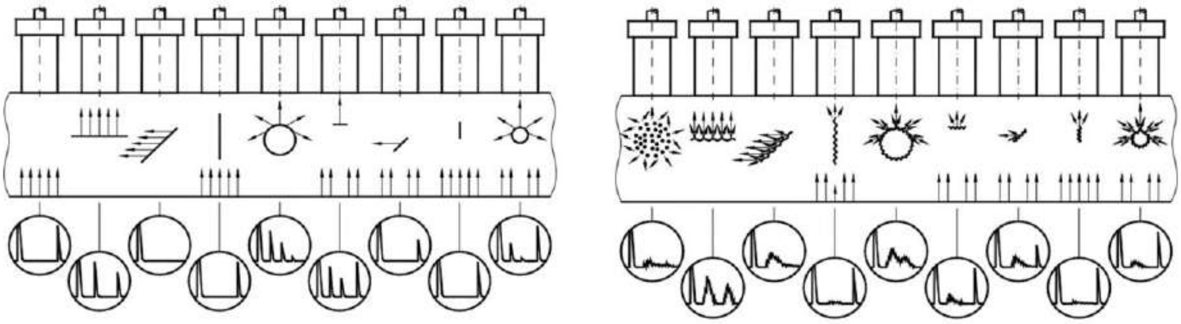


Figure 18 - The reflected-pulse technique

When using the reflected-pulse technique, the ultrasonic path is the shortest distance between the control surface and the reflector and is used to calculate the location of the reflector. However, the physical ultrasonic path is twice as long and describes the path from the control surface to the reflector and back. To optimize the selection of the transducer type, proper angle, or beam form, the expected type or orientation of the probable flaw must be known. This helps to ensure that the ultrasonic waves are properly directed towards the area of interest and that any potential flaws are detected with accuracy.

The reflected-pulse technique works by transmitting ultrasonic pulses into the material being inspected, which are then reflected back when they encounter an imperfection. These reflected pulses are detected by the transducer and displayed on a screen as a waveform. The size and shape of the waveform can be used to determine the size, shape, and location of the imperfection. The reflected-pulse technique is widely used in the inspection of welded joints, castings, forgings, and other components. It is an effective way to detect surface and subsurface defects, such as cracks, porosity, and inclusions. In this technique, the operator moves the transducer over the surface of the material being inspected, and the waveform is monitored in real-time. Any changes in the waveform can be an indication of an imperfection. The operator can adjust the angle and position of the transducer to obtain a better view of the imperfection.

2.7.2.1. Techniques Straight Beam

Ultrasonic testing uses different techniques to inspect materials and locate imperfections such as cracks, voids, or inclusions. Ultrasonic testing techniques are widely used to detect flaws in various materials. One such technique is the straight beam technique, which is used to locate flaws beneath the surface. The depth of the reflection can be calculated by knowing the speed of the ultrasonic pulse.

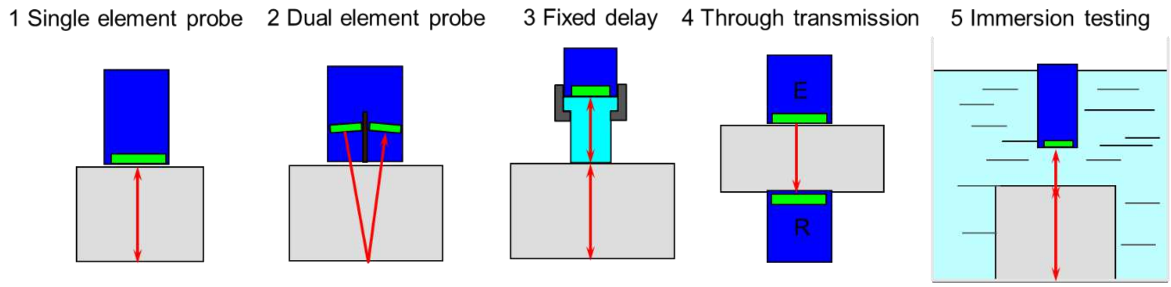


Figure 19 - Ultrasonic testing techniques

There are various pulse-echo techniques, such as using a single probe, a dual probe, or an intermediary wedge. These techniques are used for thickness measurement, near surface flaw detection, and inspection of thin sections, curved parts, tubing, and pipes. Through-transmission technique is used to assess the quality of a material by transmitting ultrasonic waves through the entire material section, and immersion technique is used by immersing the test object and the probe in a liquid medium. The through-transmission technique is used for automated inspection of plates, beams, and raw materials. This technique involves transmitting ultrasonic waves through the entire material section using a transmitter probe on one side and a receiver probe on the opposite side. The immersion technique involves immersing both the test object and the probe in a liquid coupling medium. The inspection can be total or partial using fluid flow. This technique is typically used for automated inspection. These techniques are used for plate, pipe, beam, raw material, flaw detection, welds, wall thickness, corrosion, erosion, and automated inspection. It is also suitable for inspection at high temperatures. The position of the imperfection can be accurately determined from the position of the echo on the screen, except for the through transmission technique. The dual probe pulse-echo technique involves the use of two probes - one for transmitting the pulse and the other for receiving the echo. This technique is suitable for detecting near-surface flaws, wall thickness, corrosion, erosion on plates and pipes, cladding, and weld overlay.

2.7.2.2. Techniques Angle Beam

Angle beam transducers are used to locate flaws in a spatially accurate manner. By using the sound path, the known speed of sound, and the angle of the sound beam, the depth of a flaw can be determined from the scanning surface. The position of the flaw is calculated based on the position of the transducer on the surface.

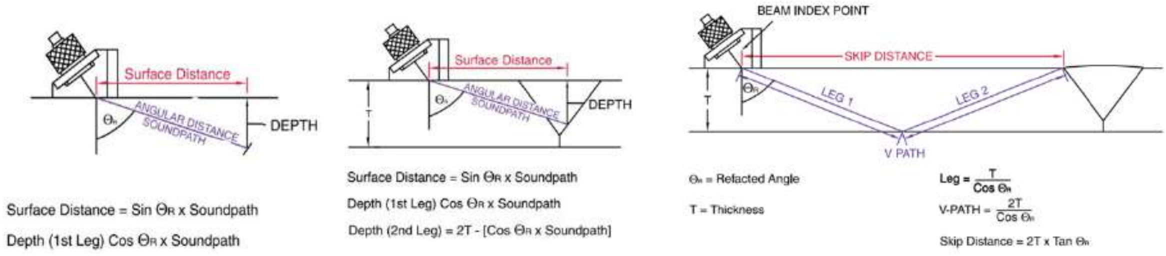


Figure 20 - Angle beam transducers

If there are multiple reflections of the beam between parallel surfaces, the position of the flaw can still be determined through calculations. Digital equipment allows for instantaneous calculations, but the system must first be calibrated. All calculations are based on the exact value of the sound path. Unlike straight beam transducers, angle beam transducers require two probes and are used for weld inspection and thickness measurement. They are commonly used in the aerospace, oil and gas, and nuclear industries.

2.7.2.3. Techniques Angle Beam or type of scanning

The tandem technique is a type of scanning that involves using two angle-beam probes with the same angle, facing in the same direction, and having their ultrasonic beam axes in the same plane perpendicular to the test surface. One probe is used for transmission, and the other is used for reception. If a signal is caught by the received probe, it indicates the presence of a reflector in the area of interest. This technique is mainly used for flaw detection and weld inspection, and it is commonly used in automated inspections of plates, pipes, beams, and raw materials. However, it provides less information about the position of the flaw.

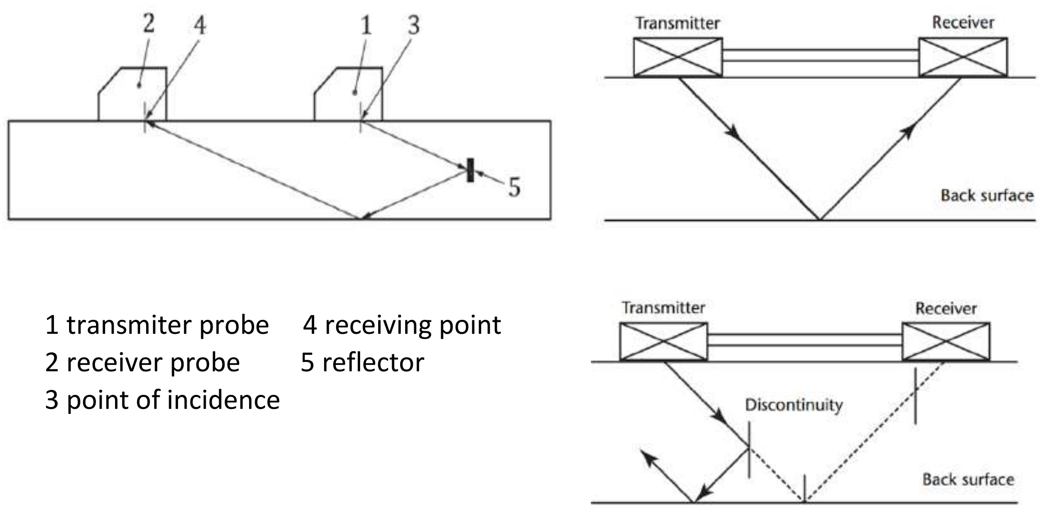


Figure 21 - The Tandem technique and the Pitch Catch technique

The Pitch Catch technique also uses two probes, but they face each other. The first probe transmits a sound beam in the plate that is caught by the receiver probe. The distance between the two probes must be calibrated so that the received signal becomes maximum. If there is a discontinuity, the sound beam is deflected and skips reaching the receiving probe, causing the signal to lose amplitude or disappear entirely. The angles and distance between the two probes are carefully calculated in relation to the thickness of the plate. This technique is mainly used for detecting discontinuities perpendicular to the test surface and is often used with a fixing mounting system for the probes. Similar to the tandem technique, this technique also provides less information about the position of the flaw.

Calibration straight

When using any type of transducer, the calibration range must be large enough to display a received signal on the horizontal screen. During calibration, the measurement origin is set on the contact surface by compensating for the time it takes for the beam to exit the transducer's wedge, known as delay, measured in µs. The speed of ultrasound in a specific material and type of vibration produced by the transducer is also set, measured in m/s. Calibration is achieved by adjusting these two values on the signals produced at known or measured distances from a calibration block with the same ultrasonic velocity, either manually or automatically.

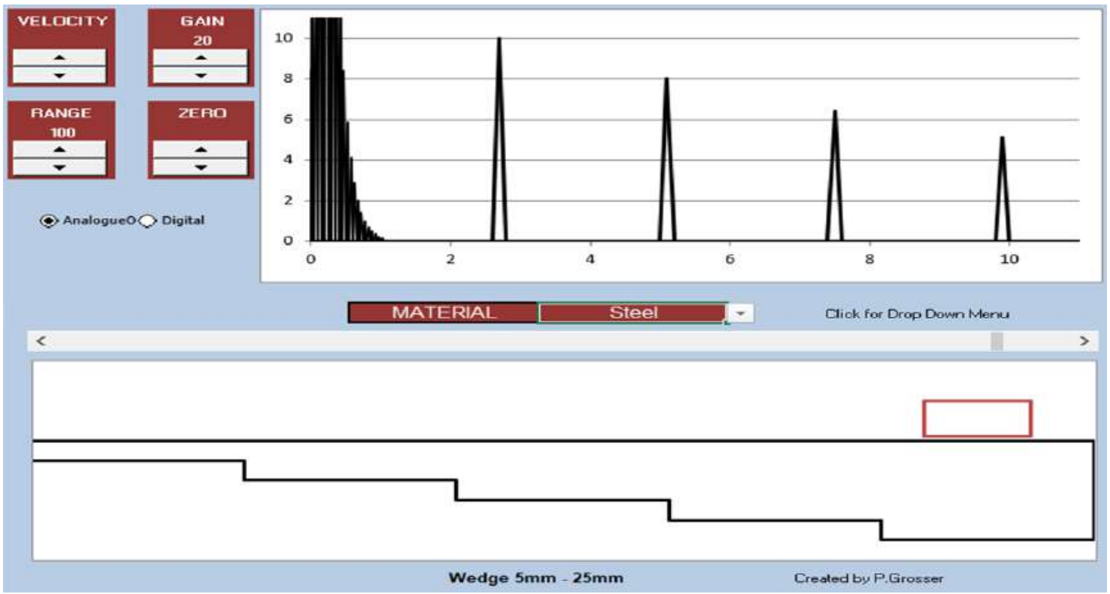


Figure 22 - Calibration of transducers

For straight beam transducers, a flat parallel piece of material is all that is required for calibration. Two pieces of different thickness or repeated echoes of the same piece can be used. Calibration ensures the accuracy of the testing process and improves the reliability of flaw detection.

Calibration angular

When calibrating straight beam transducers, a flat parallel piece of material can be used for calibration, while angular transducers require a different approach. The arc circle is the best shape for repetitive reflection when calibrating angular transducers as it eliminates the effect of angle values. A calibration body with a specific ultrasonic velocity and known dimensions is needed for this type of transducer calibration.

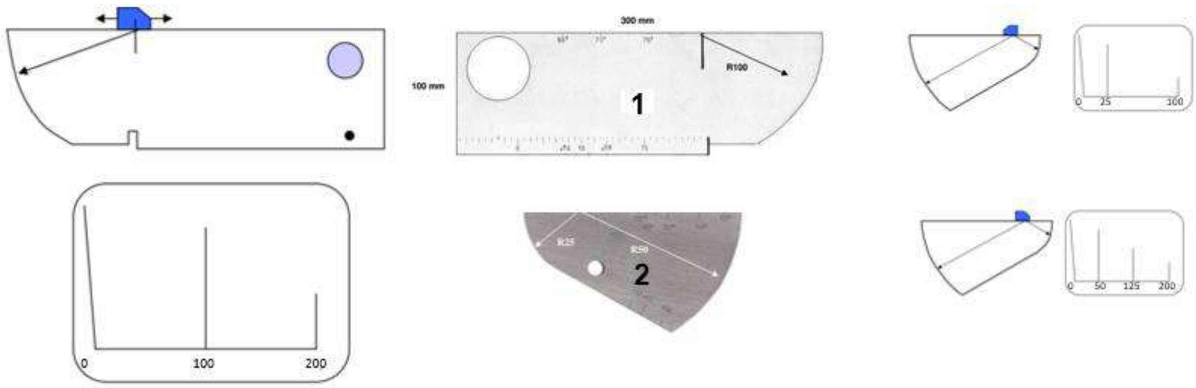
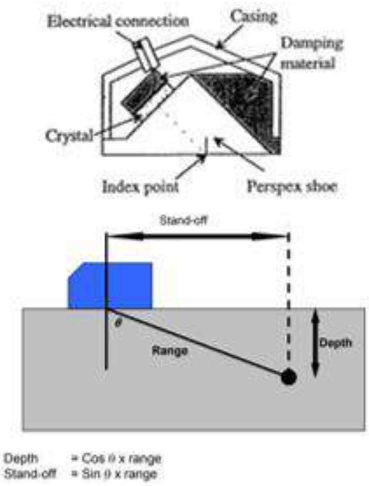


Figure 23 - Calibrating angular for transducers

For distance calibration, two calibration blocks are commonly used: Calibration Block No. 1 according to ISO 2400 and Calibration Block No. 2 according to ISO 7963. In both cases, the echoes that appear on the screen must first be maximal to ensure the right sound path. The correct shape of the screens is provided in the calibration standards.

Calibration is important to set the measurement origin on the contact surface and to compensate for the time necessary for the beam to exit from the transducer's wedge, also known as delay. Delay is measured in microseconds, and the speed of ultrasound in a specific material is measured in meters per second. By adjusting these two values on signals produced at a known or measured distance from the calibration block with the same ultrasonic velocity, calibration is done manually or automatically.

In ultrasonic testing using angular transducers, it is important to check the probe index point and the real angle in addition to the delay and speed settings. Calibration block No. 1 according to ISO 2400 is used to perform these checks.



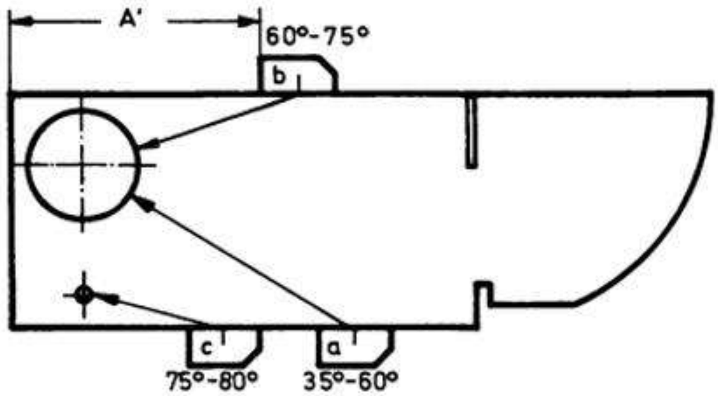


Figure 24 - Ultrasonic testing using angular transducers

The probe index point refers to the point where the sound beam axis intersects with the probe contact surface. It is crucial to locate this point accurately because it affects the accuracy of determining the position of the reflector. Another important factor to consider is the actual probe angle. The nominal (constructive) angle is the angle specified by the manufacturer, but the actual angle may differ due to wear of the contact surface. To ensure accurate calculations and positioning of reflectors, it is necessary to determine the actual probe angle. By checking both the probe index point and the real angle using the calibration block, technicians can ensure that their ultrasonic testing equipment is properly calibrated and that they are obtaining accurate results.

2.7.2.4. Sensitivity calibration

When examining a reflector, additional information about its characteristics can be obtained by reading the echo height and amplitude from the display, in addition to its position. The echo height is affected by various factors such as the control system, the object being inspected (surface condition, material), distance, shape, orientation, and size of the reflector. To account for the effects of different apparatus systems, echo heights are not measured absolutely but rather relatively, by comparing them to known reflectors of similar dimensions (comparison reflectors).

Type	Characteristics	Uses
Solid sphere	omnidirectional reflector	transducer sound field assessment
Notches	flat, corner reflector	simulation of near surface cracks
Flat bottom hole	disk reflector	reference gain
Side drilled hole	cylindrical reflector	calibration for distance amplitude correction

Commonly used comparison reflectors include notches, flat-bottom holes (FBH), and side-drilled holes (SDH), which have specific dimensions depending on the required sensitivity. To enable comparison over the entire sound path, a curve, called a comparison curve, must be plotted.

Sensitivity calibration, DAC curve, DGS diagram

The DAC curve, or distance-amplitude curve, is a reference curve that is constructed by plotting the peak amplitude responses of identical reflectors located at different distances from the probe in the same material. This allows for an unknown reflector to be characterized based on its amplitude reported to DAC and its decibel difference. The decibel difference can be negative if the reflector is smaller than the SDH, or positive if it is larger. Schematic plotting of DAC curves for SDHs with straight beam and angular transducers are presented in the figures.

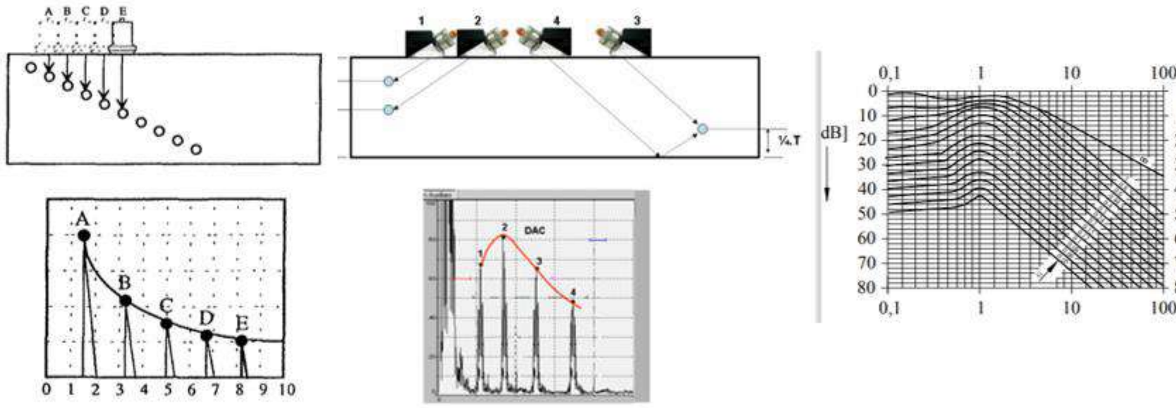


Figure 25 - The DAC curve and the DGS diagram

The DGS diagram, or distance-gain-size diagram, is a series of curves that show the relationship between distance along the beam axis and gain in decibels for an infinite reflector and for different sizes of disc-shaped reflectors. This diagram is specific to a particular transducer in terms of size, frequencies, and producer. In addition to estimating the decibel difference, the DGS can also estimate the equivalent size of a flat bottom hole (FBH) disc shape that can produce a similar reflection in the same condition. Both DAC and DGS are primarily used to estimate the size of small reflectors in comparison with the width of the sound beam at the same distance.

2.7.2.5. Sizing up defects

When determining the size of large reflectors relative to the diameter of the ultrasonic beam, scanning their edges is a common technique. This involves moving the probe from a position that optimizes the echo of the defect towards the edge of the defect, marking the point where the echo height decreases by a specific drop, which indicates where the central beam meets the edge of the defect. Multiple measurements are taken to determine the outline of the reflector length or surface and obtain a good approximation of its size.

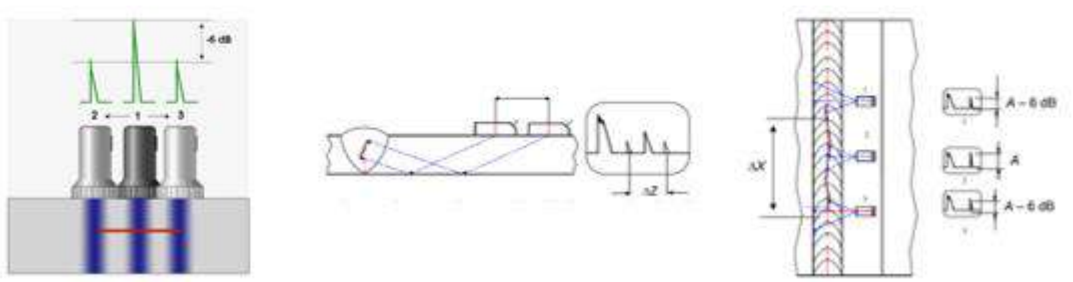


Figure 26 - The common techniques for sizing

There are two common techniques for sizing: the 6 dB drop technique (also known as half amplitude or beam splitting technique) and the 20 dB drop technique (also known as beam boundary technique). The halving length is the distance measured on the object between edge points in the length direction Δx, while the halving width is the same but in the width direction Δz. If the -20 dB drop technique is used, the determined length will be larger than that obtained using the -6 dB drop technique. After a reflector has been located and sized, it can be precisely measured for acceptability. Its size is determined as dB over DAC/DGS, or with specific dimensions if larger, and compared with acceptable limits. Based on this comparison, a conclusion is reached whether to accept or reject the reflector.

2.7.3. Limitation of the test techniques

Ultrasound testing has its own set of advantages and disadvantages.

Advantages:

- Quick, portable, and safe method of testing.
- Provides instant information on the object being tested.
- Can penetrate thick sections of over 150mm.
- Only requires access from one side of the material and requires less surface preparation.
- Can measure depth and through-wall extent of defects.
- Sensitive to cracks and lack of fusion at various orientations if proper angles are used.
- Has reduced operating costs compared to other non-destructive testing methods.
- Can be automated for greater efficiency.

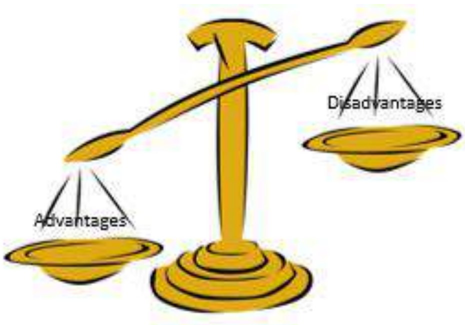


Figure 27 - The advantages and disadvantages of Ultrasound testing

Disadvantages:

- Requires a skilled operator who has knowledge and information about the object being inspected.
- Relies on the orientation of defects in the object.
- Limited to thicker sections, with a minimum thickness of around 8mm.
- Does not create a permanent record of the inspection unless it is automated.
- Not easily applied to complex geometries and rough surfaces.
- Unsuitable for coarse-grained and non-homogeneous materials.

2.7.4. UT of welds ISO 17640, ISO 11666

ISO 17640 and ISO 11666 are important standards that provide guidelines for ultrasonic testing of welds in metallic materials. ISO 17640 focuses on the techniques used for manual ultrasonic testing of full penetration welded joints where both the welded and parent material is ferritic. It specifies four testing levels: A, B, C, and D, which are based on the probability of detecting imperfections. These testing levels help to ensure that welds are tested at a level appropriate for their intended use.

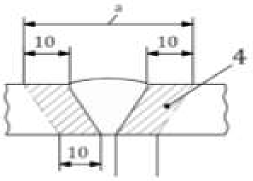
Quality level in accordance with ISO 5817	Testing technique and level in accordance with ISO 17640[a]	Acceptance level in accordance with ISO 11666
B	at least B	2
C	at least A	3
D	at least A	4[b]

a When characterization of indications is required, ISO 23279 shall be applied.
b UT is not recommended but can be defined in a specification (with the same requirements as quality level C).

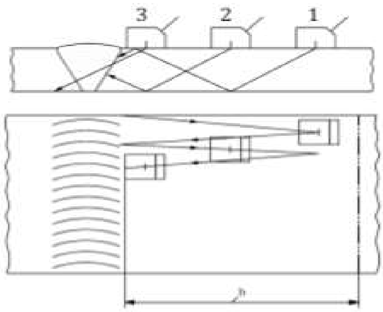
On the other hand, ISO 11666 specifies two acceptance levels, 2 and 3, which correspond to ISO 5817 quality levels B and C, respectively. The acceptance levels are intended for welds with thicknesses ranging from 8 mm to 100 mm, and they provide guidance on the acceptable limits for the size and number of imperfections that may be present in the weld. This helps to ensure that welds meet the required quality standards for their intended use. It is important to note that both ISO 17640 and ISO 11666 require skilled operators to perform the ultrasonic testing and interpret the results. The standards also have limitations, and the testing may not be suitable for all types of materials, geometries, or defect orientations. Overall, these standards are crucial for ensuring the quality and reliability of welded structures in various industries.

ISO 17640 is a standard that outlines the general techniques for ultrasonic testing of welded joints, using standard criteria for the most commonly used welded joints at object temperatures ranging from 0°C to 60°C. The standard specifies specific requirements for test equipment, preparation, performance of testing, and reporting.

The testing volume, as defined in the standard, includes the zone that encompasses the weld and parent material, as well as the width of the Heat Affected Zone (HAZ) on each side of the weld. The frequency of the transducers used for testing shall be within the range of 2 MHz to 5 MHz and should be selected based on the properties of the test object.



Width of testing volume



Scanning zone width, from both sides

Figure 28 - Width of testing volume and scanning zone width

The angle between the beam and the normal to the opposite reflecting surface should be between 35° and 70°. If the use of two or more beam angles is specified, the difference between the nominal beam angles should be 10° or greater. At least one of the beam angles used should ensure that the weld fusion faces are tested at, or as near as possible to, normal incidence.

In non-destructive testing, there are three commonly used techniques for evaluating the size of a reflector.

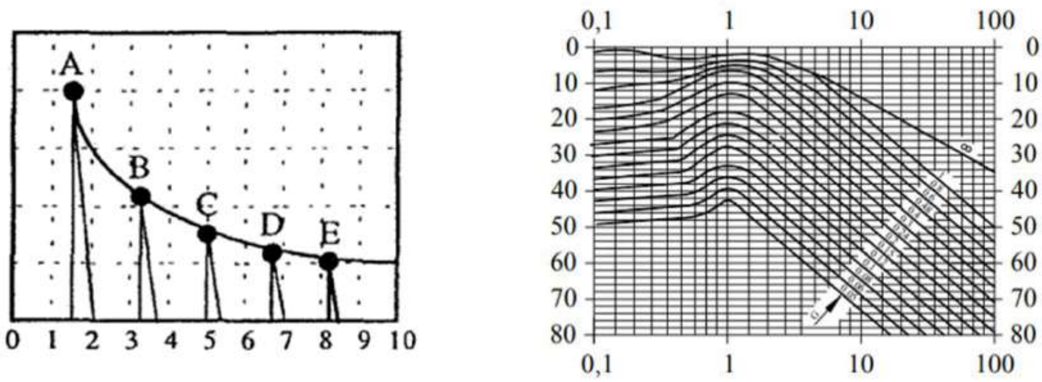


Figure 29 - Techniques for evaluating the size of a reflector.

The first technique involves using a distance-amplitude curve (DAC) for side-drilled holes with a diameter of 3 mm as a reference. The second technique involves using the distance-gain-size (DGS) system to create references for transverse and longitudinal waves, based on the precise diameter of the flat-bottomed hole (FBH) reflectors, which varies depending on the frequency and thickness of the material being tested. The third technique involves using a rectangular notch as a reference, which is 1 mm wide and 1 mm deep, but this technique is only applicable for material thicknesses ranging from 8 mm to less than 15 mm and for beam angles greater than or equal to 70 degrees. These techniques allow for the accurate evaluation of reflector size during ultrasonic testing.

Testing levels in ultrasonic testing of welds refer to the degree of coverage and probability of detecting imperfections in the welded joint. The levels are designated as A, B, C, and D, with each level corresponding to a different probability of detection. Increasing the testing level from A to C is achieved by increasing the testing coverage, which includes the number of scans and the degree of surface preparation. Testing level D is reserved for special applications and requires a specific written procedure.

Testing level	Quality level in ISO 5817
A	C, D
B	B
C	By agreement
D	Special application

The testing level required for a particular weld inspection may be specified in relevant standards for testing of welds, product standards, or other documents. The appropriate testing level is determined based on the criticality of the weld and the required level of quality. Testing at a higher level may be necessary for critical applications where safety is paramount, while lower levels may be acceptable for less critical applications. The testing technique used for ultrasonic testing of welds involves a manual scan path, where the angle-beam scanning technique is employed. During the scanning process, a slight swivelling movement of up to approximately 10° on either side of the nominal beam direction should be applied to the probe. This technique helps to ensure adequate coverage of the weld and increases the probability of detecting any imperfections.

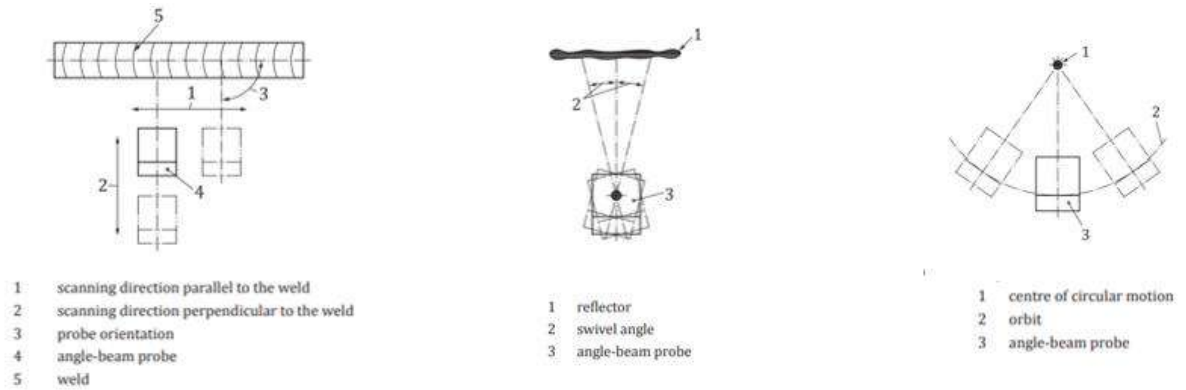


Figure 30 - The testing technique

When scanning for longitudinally oriented defects, the beam must be oriented perpendicular to the weld axes. This orientation allows the beam to propagate through the length of the weld, increasing the probability of detecting any defects that may be present. On the other hand, if there is a need to scan for transverse discontinuity, the angle beam transducer should be oriented as parallel as possible with the weld longitudinal axes. This orientation helps to ensure that the beam is directed at an angle that is most likely to detect any transverse defects that may be present in the weld. Overall, these testing techniques help to ensure that the entire weld is adequately covered during ultrasonic testing, increasing the probability of detecting any defects that may be present.

To test butt joints of plate or pipes using ultrasonic testing of welds, the appropriate testing level and common type of weld must be determined. The minimum number of scans, positions, type of transducer, and angles required are specified in figures and tables, which take into account the thickness of the base material.

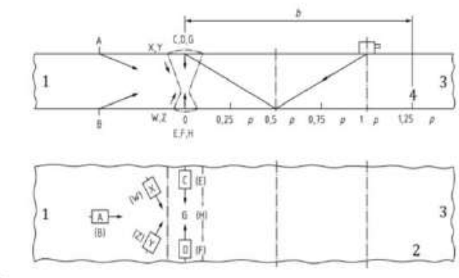


Table A.1 — Butt joints in plates and pipes

Testing level	Thickness of the parent material (mm)	Longitudinal discontinuities: Required number of — Beam angles (L-scans)	Probe positions (L-scans)	Scanning zone width (L-scans)	Probe positions (N-scans)	Total number of scans	Notes	Transverse discontinuities: Required number of — Beam angles (T-scans)	Probe positions (T-scans)	Total number of scans	Notes
A	8 ≤ t < 15	1	A or B	1,25 p	—	2	a	1	(X and Y) or (W and Z)	4	c
	15 ≤ t < 40	1	A or B	1,25 p	—	2	a	1	(X and Y) or (W and Z)	4	c
B	8 ≤ t < 15	1	A or B	1,25 p	—	2	a	1	(X and Y) or (W and Z)	4	c
	15 ≤ t < 40	2[f]	A or B	1,25 p	—	4	b,e	1	(X and Y) or (W and Z)	4	c
	40 ≤ t < 60	2	A or B	1,25 p	—	4	b	2	(X and Y) or (W and Z)	8	c
	60 ≤ t ≤ 100	2	A or B	1,25 p	—	4	b	2	(C and D) or (E and F)	4	c,d
C	8 ≤ t < 15	1	A or B	1,25 p	G or H	3	d	1	(C and D) or (E and F)	2	d
	15 ≤ t ≤ 40	2	A or B	1,25 p	G or H	5	b,d	2	(C and D) or (E and F)	4	d
	>40	2	A or B	1,25 p	G or H	5	b,d	2	(C and D) or (E and F)	4	d

Figure 31 - The minimum number of scans, positions, type of transducer, and angles

The minimum conditions are established for both longitudinally and transversely oriented discontinuities. As the thickness and testing level increase, so does the number of scans and required angles. The preferred approach for ultrasonic testing of welds in structural T joints is to use a normal transducer and explore from the C direction. However, if exploration from the A or B direction is necessary, the proper angle should be used. It is important to note that the angle of exploration may differ depending on the type of weld and the thickness of the base material.

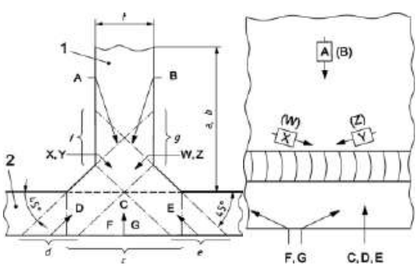


Table A.2 — Structural T-joints

Testing level	Thickness of the parent material (mm)	Longitudinal discontinuities: Required number of — Beam angles (L-scans)	Probe positions (L-scans)	Scanning zone width (L-scans)	Probe positions (N-scans)	Scanning zone width (N-scans)	Total number of scans	Transverse discontinuities: Required number of — Beam angles (T-scans)	Probe positions (T-scans)	Scanning zone width (T-scans)	Total number of scans	Notes
A	8 ≤ t < 15	1	A or B	1,25 p	C[c]	—	1	—	—	—	—	a
	15 ≤ t < 40	1	A or B	1,25 p	C[c]	c	2	—	—	—	—	a
B	8 ≤ t < 15	1	A or B	1,25 p	C[c]	—	2	1	F and G	c	2	b
	15 ≤ t < 40	1	A and B	1,25 p	C[c]	c	3	1	(F and G) or (X and Y) or (W and Z)	c f + g	2	b
	40 ≤ t ≤ 100	2	A and B	0,75 p	C[c]	c	5	1	(F and G) or (X and Y) or (W and Z)	c f + g	2	b

Figure 32 - Ultrasonic testing of welds in structural T joints

The recommended technique for ultrasonic testing of set-through nozzle joints in welds is to use a normal transducer and explore from the C direction, if possible.

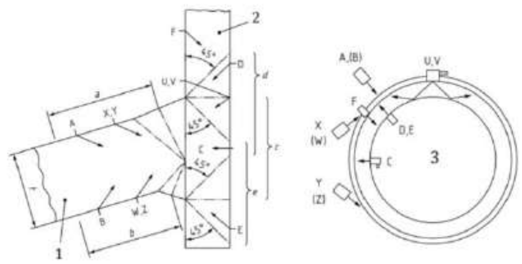


Table A.3 — Set-through nozzle joints

Testing level	Thickness of the parent material (mm)	Longitudinal discontinuities: Required number of — Beam angles (L-scans)	Probe positions (L-scans)	Scanning zone width (L-scans)	Probe positions (N-scans)	Scanning zone width (N-scans)	Total number of scans	Transverse discontinuities: Required number of — Beam angles (T-scans)	Probe positions (T-scans)	Total number of scans	Notes
A	$8 \le t < 15$	1	A	1,25 p	C	c	1	—	—	—	a
	$15 \le t \le 40$	1	A or F or D	1,25 p d	C	c	2	—	—	—	a
B	$8 \le t < 15$	1	A or D	1,25 p d + e	C	c	2	1	(U and V) or (X and Y) or (W and Z)	2	b
	$15 \le t < 40$	1	A or (D and E)	1,25 p d + e	C	c	2 or 3	1	(U and V) or (X and Y) or (W and Z)	2	b
	$40 \le t < 60$	1	(A or B) and (D and E)	1,25 p d + e	C	c	4	1	(X and Y) and (W and Z)	4	b
	$60 \le t \le 100$	2 1	(A and B) and (D and E)	0,5 p d + e	C	c	7	2	(X and Y) and (W and Z)	8	b
C	$8 \le t < 15$	1	(A or B) and (D or E)	1,25 p d or e	C	c	3	1	(U and V) or (X and Y) and (W and Z)	2 or 4	b
	$15 \le t \le 40$	2	(A or B) and (D or E)	0,5 p d or e	C	c	5	2	(X and Y) and (W and Z)	8	b
	>40	2	(A or B) and (D or E)	0,5 p d + e	C	c	9	2	(X and Y) and (W and Z)	8	b

Figure 33 - Technique for ultrasonic testing of set-through nozzle joints in welds

The recommended technique for ultrasonic testing of welds in structural L joints is to use a normal transducer and explore from the C direction, if possible. This is because the C direction is often the most accessible surface for exploration. However, the approach for testing may vary depending on the available surfaces for exploration. Other methods may be used if the C direction is not accessible. It is important to choose the appropriate technique for each joint to ensure accurate testing results.

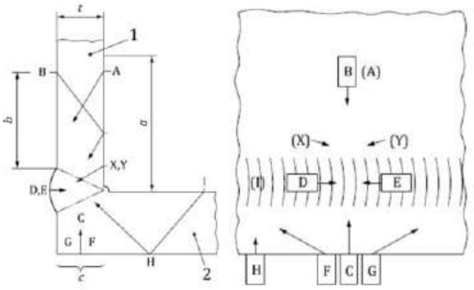


Table A.4 — Structural L-joints

Testing level	Thickness of the parent material (mm)	Longitudinal discontinuities: Required number of — Beam angles (L-scans)	Probe positions (L-scans)	Scanning zone width (L-scans)	Probe positions (N-scans)	Scanning zone width (N-scans)	Total number of scans	Transverse discontinuities: Required number of — Beam angles (T-scans)	Probe positions (T-scans)	Total number of scans	Notes
A	$8 \le t < 15$	1	A or B or H	1,25 p	C	c	1	—	—	—	a
	$15 \le t \le 40$	1	A or B or H	1,25 p	C	c	2	—	—	—	a
B	$8 \le t < 15$	1	A or B or H	1,25 p	C	c	1	1	(F and G) or (X and Y)	2	b
	$15 \le t < 40$	2	A or B or H	1,25 p	C	c	3	2	(F and G) or (X and Y)	4	b
	$40 \le t \le 100$	2	(H or A) and B	0,75 p	C	c	5	2	D and E	4	b,c
C	$8 \le t < 15$	1	(H or A) and B	1,25 p	C	c	3	1	D and E	2	b,c
	$15 \le t < 40$	2	(H or A) and B	1,25 p	C	c	5	1	D and E	2	b,c
	$40 \le t \le 100$	3	(H or A) and B	1,25 p	C	c	7	2	D and E	4	b,c
	> 100	3	(H or A) and B	0,5 p	C	c	7	2	D and E	4	b,c

Figure 34 - Ultrasonic testing of welds in structural L joints

Ultrasonic testing of welds in nozzle joints is best performed by using a normal transducer to explore from the C direction. However, in cases where the pipe diameter is small, it may be necessary to modify the angular transducers to fit the curvature of the joint.

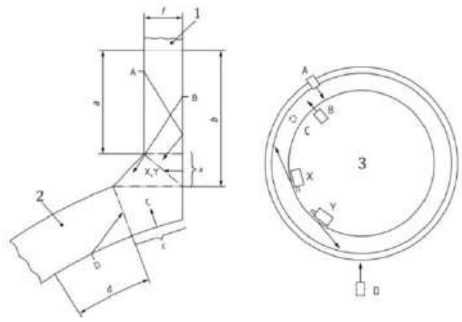


Table A.5 — Set-on nozzle joints

Testing level	Thickness of the parent material (mm)	Longitudinal discontinuities: Required number of — Beam angles (L-scans)	Probe positions (L-scans)	Scanning zone width (L-scans)	Probe positions (N-scans)	Scanning zone width (N-scans)	Total number of scans	Transverse discontinuities: Required number of — Beam angles (T-scans)	Probe positions (T-scans)	Total number of scans	Notes
A	$8 \le t < 15$	1	A or B	1,25 p 0,50 p	—	—	1	—	—	—	a
	$15 \le t \le 40$	1	A or B	1,25 p 0,50 p	C	c	2	—	—	—	a
B	$8 \le t < 15$	2	A or B	1,25 p 0,50 p	—	—	2	1	X and Y	2	b,c
	$15 \le t < 40$	2	A or B	1,25 p 0,50 p	C	c	3	1	X and Y	2	b,c
	$40 \le t < 60$	2	A and (B or D)	1,25 p 0,50 p	C	c	5	2	X and Y	4	b,c
	$60 \le t \le 100$	2	A and (B or D)	1,25 p 0,5 p	C	c	5	2	X and Y	4	b,c

Figure 35 - Ultrasonic testing of welds in nozzle joints

In cruciform joints, the weld geometry can cause reflection of ultrasonic waves, which can make it challenging to detect defects accurately. Therefore, it is crucial to carefully choose the angles of the transducers to ensure that the beam is directed perpendicularly to the joint preparation, which can help reduce the reflections and increase the accuracy of defect detection.

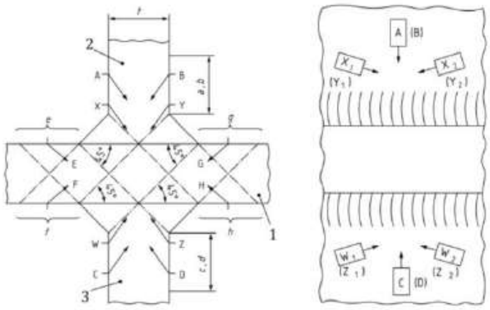
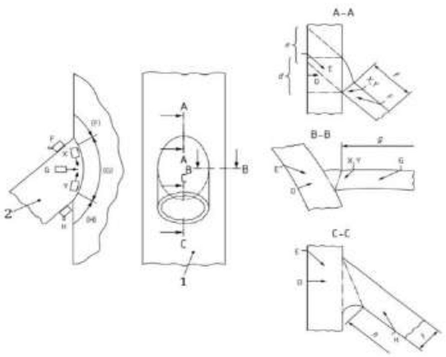


Table A.6 — Cruciform joints

Testing level	Thickness of the parent material (mm)	Longitudinal discontinuities: Required number of — Beam angles (L-scans)	Probe positions (L-scans)	Scanning zone width (L-scans)	Total number of scans	Notes	Transverse discontinuities: Required number of — Beam angles (T-scans)	Probe positions (T-scans)	Total number of scans	Notes
A	8 ≤ t < 15	1	(A and C) or (B and D)	1,25 p	2	—	—	—	—	a
	15 ≤ t < 40	1	A and B and C and D	0,75 p	4	c	—	—	—	a
	40 ≤ t ≤ 100	2	A and B and C and D	0,75 p	8	c	—	—	—	—
B	8 ≤ t < 15	1	A and B and C and D	1,25 p	4	—	1	(X_1 and Y_1 and W_1 and Z_1) and (X_2 and Y_2 and W_2 and Z_2)	8	b
	15 ≤ t < 40	2	A and B and C and D	0,75 p	8	c	1	(X_1 and Y_1 and W_1 and Z_1) and (X_2 and Y_2 and W_2 and Z_2)	8	b
	40 ≤ t ≤ 100	2 1	(A and B and C and D) and (E and F and G and H)	0,75 p e − h	12	d g	2	(X_1 and Y_1 and W_1 and Z_1) and (X_2 and Y_2 and W_2 and Z_2)	16	b
C	40 ≤ t ≤ 100	2 1	(A and B) and (C and D) and (E and F) and (G and H) and tandem (A or B) and (C or D)	0,75 p e − h	14	—	2	(X_1 and Y_1 and W_1 and Z_1) and (X_2 and Y_2 and W_2 and Z_2)	16	b

Figure 36 - The weld geometry in cruciform joints

The node of tubular structures typically presents a more complicated geometry than other types of welds, which can make it more difficult to obtain accurate and reliable ultrasonic testing results. The use of modified angular transducers may be necessary to ensure proper examination of the weld, especially if the pipe diameter is small. In addition, the examination of this type of joint typically requires more preparation of the equipment and expertise on the part of the operator. Overall, ultrasonic testing of node welds in tubular structures requires careful attention to detail and specialized knowledge and skills.



Testing level	Thickness of the parent material (mm)	Longitudinal indications: Required number of — Probe angles (L-scans)	Probe positions (L-scans)	Scanning zone width (L-scans)	Probe positions (N-scans)	Scanning zone width (N-scans)	Total number of scans	Transverse indications: Required number of — Probe angles (T-scans)	Probe positions (T-scans)	Total number of scans	Notes
A	8 ≤ t < 15	1	A or B	1,25 p 0,50 p	—	—	1	—	—	—	a
	15 ≤ t ≤ 40	1	A or B	1,25 p 0,50 p	C	c	2	—	—	—	a
B	8 ≤ t < 15	2	A or B	1,25 p 0,50 p	—	—	2	1	X and Y	2	bc
	15 ≤ t < 40	2	A or B	1,25 p 0,50 p	C	c	3	1	X and Y	2	bc
	40 ≤ t < 60	2	A and (B or D)	1,25 p 0,50 p	C	c	5	2	X and Y	4	bc
	60 ≤ t ≤ 100	2	A and (B or D)	1,25 p 0,5 p	C	c	5	2	X and Y	4	bc
C	8 ≤ t < 15	3	A or B	1,25 p 0,5 p	C	c	4	1	X and Y	2	bc
	15 ≤ t < 40	3	A or B	1,25 p 0,5 p	C	c	4	1	X and Y	2	bc
	40 ≤ t < 60	3	A and B	1,25 p 0,5 p	C	c	7	2	X and Y	4	bc
	60 ≤ t ≤ 100	3	A and B	1,25 p 0,5 p	C	c	7	2	X and Y	4	bc

Figure 37 - Ultrasonic testing of node welds in tubular structures

ISO 11666 specifies the requirements and provides guidance for ultrasonic testing of ferritic steel welds. The standard defines different quality levels based on the size and severity of defects in the weld. The evaluation criteria for each quality level differ, and the level of acceptance for each criterion is also defined. Acceptance level 2 is used for detecting defects that are considered harmful, and level 3 is used for detecting defects that are considered less harmful. The evaluation criteria for both levels are based on the maximum amplitude and length of the reflector. There are four ways of setting the sensitivity for ultrasonic testing based on comparison curves, as specified in ISO 17640. These curves are used to establish the minimum detectable size of a defect based on its location in the weld and the orientation of the ultrasonic beam.

Quality level in accordance with ISO 5817	Testing technique and level in accordance with ISO 17640[a]	Acceptance level in accordance with ISO 11666
B	at least B	2
C	at least A	3
D	at least A	3[b]

[a] When characterization of indications is required, ISO 23279 shall be applied.
[b] UT is not recommended but can be defined in a specification (with the same requirements as quality level C).

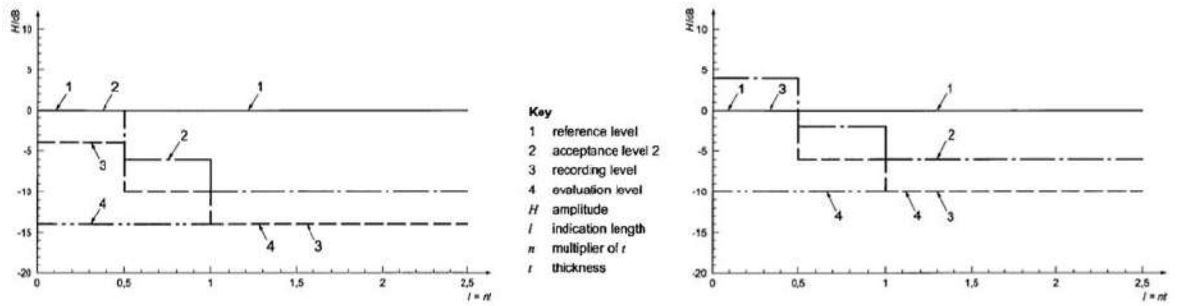
technique 1: based on 3 mm diameter side-drilled holes;

technique 2: based on distance gain size (DGS) curves for flat-bottom holes (disk-shaped reflectors);

technique 3: using a distance-amplitude-corrected (DAC) curve of a rectangular notch of 1 mm depth and 1 mm width;

technique 4: using the tandem technique with reference to a 6 mm diameter flat-bottom hole (disk-shaped reflector).

The maximum signals obtained through reflection during ultrasonic testing must be characterized as a difference in decibels relative to the reference level, depending on the technique used. There are different levels defined to facilitate the selection and evaluation of ultrasound responses: the evaluation level, recording level, and acceptance level. These levels must be used in conjunction with the determined length of the reflector (defect/flaw). If the length of the reflector exceeds half of the base material thickness, the levels are reduced, and the height of the signal must be smaller to be accepted. All reflectors that exceed the recording level must be reported in the examination report with details regarding position, length, and signal height characterization. Any reflectors that exceed the acceptance level are to be rejected.



Levels for technique 1 for thicknesses 15 mm to 100 mm — Acceptance level 2

Levels for technique 1 for thicknesses 15 mm to 100 mm — Acceptance level 3

Figure 38 - Levels for technics 1 for thickness 15 mm to 100 mm – acceptance level 2 and 3

If you are looking for more information about the type of the defects that are found during the UT inspection, there is ISO 23279: Non-destructive testing of welds-Ultrasonic Testing-Characterization of discontinuities in welds, with specification about how to classify these echoes originating from planar or non-planar embedded discontinuities.

There are some basic echo static and echo dynamic pattern that can be used for this characterization.

Pattern 1, a point- like reflector show a single sharp echo. As the probe is moved, it rise in amplitude smoothly to single maximum before falling smoothly.

Pattern 5, a multiple reflector shows a cluster of signals which may or may not be well-resolved in range. As the probe is moved, the signals rise and fall in amplitude in a random way, the signals of each reflector show a pattern 1 response.

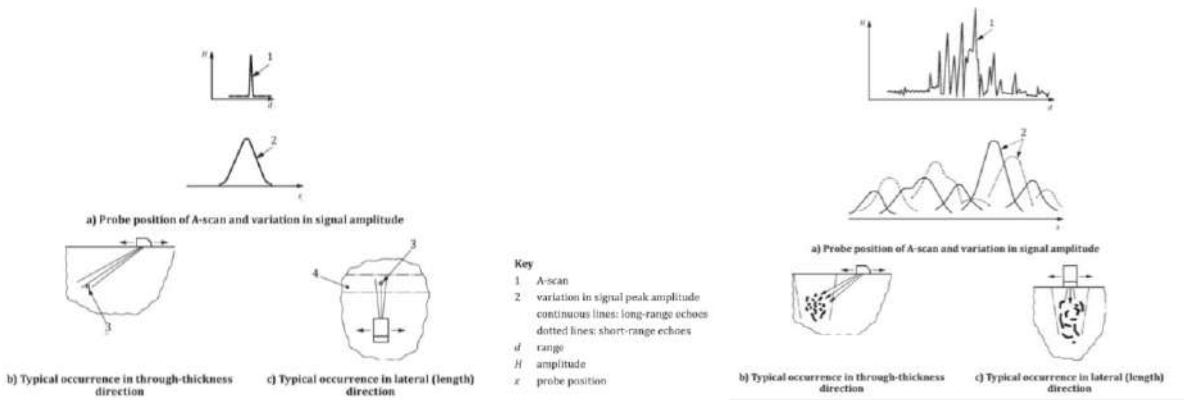


Figure 39 - Pattern 1 point-like reflector (left) and Pattern 5 multiple reflector (right) response

Pattern 2, an extended smooth reflector response, show a single sharp echo, when the beam is moved over the reflector, the echo rise to a plateau, and then falls smoothly in booth scanning directions.

Pattern 3, an extended rough reflector response, at near normal incidence show a single ragged echo, when the beam is moved over the reflector, the echo have random amplitude fluctuation that are caused by reflections from different facets and positions, of the reflector.

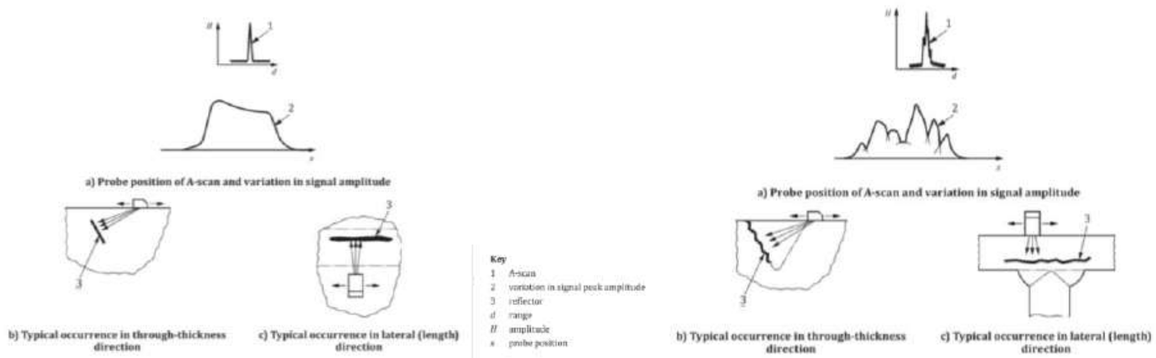


Figure 40 - Pattern 2 extended smooth reflector (left) and Pattern 3 extended rough reflector (right) response

Pattern 4, an extended rough reflector response, at oblique incidence show an extended train of signals "travelling echoes" with subsidiary peaks all forming a bell-shaped pulse envelope. When the beam is moved over the reflector, each peak shows a Pattern 1 shape echo with large random amplitude fluctuations.

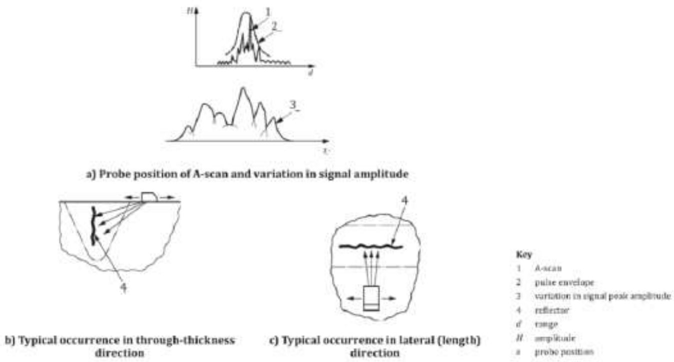


Figure 41 - Pattern 4 extended rough reflector response orientation variant

2.7.5. Reporting UT tests

The examination report must include several pieces of information, such as the identification of the examination organization and certification of the operator, place, and date of the examination, and reference standard. Additionally, the report should include details regarding the object being examined, including material and shape, dimensions, location of the examined weld/welded joint, sketch, welding procedure and configuration, heat treatment (if any), manufacturing stage, surface condition, and temperature.

Name of inspector	Inspected Item	Equipment			Technique	Results
Place of inspection	Material	Flaw Detector	Ultrasonic Probes	Ultrasonic calibration block	Testing levels	Maximum amplitude
Date of inspection/report	Configuration	Maker	Maker	Maker	Extent of test %	Coordinates
Reference standard	Stage of manufacture	Type	Type	Type	Location of scanning areas	Type
Other contractual requirements, specifications, guidelines, special agreements, if.	Dimensions		Frequency		Reference point	Dimensions
	Surface condition / temperature		Angle		Identification of probe position	Accept / Reject
	Location of weld	Serial number	Serial number	Serial number	Time base range	
	Specification				Sensitivity level	
					Reference level	
				Couplant	Parent metal examination	
				Type	Acceptance level	
					Deviations from Standard, (if necessary).	

The equipment used during the examination should also be listed, including the flaw detector, ultrasonic probes, ultrasonic calibration block, and couplant. The report should specify the applied techniques, such as the level of examination, volume of the examination, position of the exploration areas, reference points and coordinate system, identification of transducer positions, the domain of the time base, method and values used for sensitivity adjustment (gain adjustment, transfer corrections, reject, filters), reference levels, base material examination (if any), and any deviations from the standard. The result of the examination should also be included according to acceptance level, such as maximum echo amplitudes, coordinates of discontinuities, type and size of discontinuities, and lengths of discontinuities. Finally, the report should state whether the results are accepted or rejected.

CERTIFYED BY

ULTRASONIC TESTING REPORT

Name and address of the customer (beneficiary): ....

Examined object: ....

Date of object reception: ....

Date of examination: ....

Place of examination: ....

Examinations performed: ultrasonic testing**.**

Head of laboratory,

....

Operators,

....

END-0031, level ....

according to EN ISO 9712

1. **Examined object:**
   - *Name*: ………, serial number ....
   - *Materials*: ………according to drawing: ………………
2. **Performed examinations:**
   - *Examination method*: ....;
   - *Examination standard*: according to SR EN ISO 17640, ...;
   - *Examination technique*: ....;
   - *Examination volume*: ………………;
   - *Quality conditions*: according to SR EN ISO 11666, level .....;
   - *Evaluation method*: ....
   - *Registration level*: ....;
   - *Acceptability level*: according to SR EN ISO 11666, level .....
3. **Examination mode:**
   - *Place of examination:* ....;
   - *Examination technique*: ....
   - *Operator's qualification*: EN .... level ......;
   - *Surface conditions:* ………..;
   - *Ambient temperature:* …… ºC;
   - *Probe/pieces temperature:* ….. ºC
4. **Equipment / materials:**
   - *Ultrasonic flaw detector*: type ...., made by ....;
   - *Probes*: MWB70-N4 and .... made by ....;
   - *Coupling medium*: ....;
   - *Calibration block*: ....
5. **Calibration:**
   - *Calibration of distance scale*: ....;
   - *Calibration of sensibility*: made according to .... method.
6. **Examination parameters:**

- Probe: ....
- Distance range: ...... mm
- Calibration gain: ... dB
- Additional gain: .... dB
- Working gain: .... dB

- Probe: .....
- Distance range: .... mm
- Calibration gain: .... dB
- Additional gain: .... dB
- Working gain: .... dB

7. **Results:** The examined ...., ... are considered **...........** according to the requirements of ....
8. **Statement:** This Testing Report refers only at the tested pieces/welds.

....

2.8. Advanced and other NDT methods

Non-Destructive Testing (NDT) encompasses a variety of inspection techniques that enable inspectors to assess and gather information about a material, system, or component without causing permanent damage to it.

Within the industry, NDT commonly serves as an overarching term encompassing non-destructive inspection methods, inspection tools, and the broader field of non-destructive inspections. It is used to encompass the various techniques, tools, and practices employed for evaluating and examining materials, systems, or components without causing permanent alterations or damage.

The top reasons NDT is used throughout the world:

- Safety: NDT techniques are generally safe for personnel involved in the inspection process. With the exception of radiographic testing, most NDT methods do not pose any direct harm to individuals, ensuring a high level of safety during inspections.
- Accuracy: NDT methods have demonstrated their reliability in delivering accurate and predictable results. These qualities are vital in maintenance procedures aimed at ensuring the safety of personnel and the longevity of equipment. By providing precise information about the condition and integrity of materials, NDT allows for informed decision-making regarding maintenance, repairs, or replacements.
- Efficiency: NDT methods facilitate thorough and efficient evaluation of assets. By enabling rapid inspection processes, NDT contributes to enhanced productivity, timely assessments, and minimizes downtime. This efficiency is particularly crucial for maintaining safety standards and optimal performance in various job sites.
- Cost Savings: NDT offers a significant advantage over destructive testing methods as it enables the examination of materials or objects without causing harm or permanent damage. This non-destructive nature translates into cost savings by preserving the integrity and usability of the tested items, eliminating the need for costly replacements or repairs.

NDT plays a vital role in the smooth operation of a facility, and its significance is well recognized by trained inspectors. The effectiveness of NDT techniques and the reliability of results rely heavily on skilled technicians with experience and integrity. It is crucial for technicians to possess certification in the specific NDT method they are employing and have a thorough understanding of the equipment used for data collection. Profound knowledge of equipment capabilities and limitations is essential in making accurate determinations regarding acceptance or rejection of inspected materials or components. The expertise and competence of technicians are instrumental in ensuring the success and effectiveness of NDT practices within a facility.

In the following content, we will endeavour to provide a condensed overview of the challenges associated with NDT testing, considering the vast volume of material involved

Advanced NDT methods, similar to conventional NDT techniques, are non-invasive inspection methods employed to assess material properties, components, structures, and process units. These methods represent emerging technologies and, as a result, may be less comprehensively understood. In certain cases, the advantages or limitations of these advanced methods may be uncertain, and there could be a lack of standardized qualification criteria for technicians in some testing methods. Additionally, some advanced NDT techniques may lack industry-wide codification or established guidelines.

In general, the setup, procedure, and data interpretation of advanced NDT methods are more complex and often necessitate specialized knowledge and experience from a well-trained technician. These advanced techniques may involve intricate instrumentation, sophisticated analysis techniques, and nuanced interpretation of results. It is essential for technicians to undergo proper training to develop the necessary skills and expertise to effectively handle and interpret data from these advanced NDT methods. The intricate nature of these techniques underscores the importance of having qualified technicians with the requisite knowledge and experience to ensure accurate and reliable results.

2.8.1. Phased Array

Phased Array Testing, also known as phased array UT, is an advanced non-destructive testing technique that uses a set of ultrasonic (UT) testing probes made up of numerous small elements. Each of these elements is individually pulsed with computer-calculated synchronization to create the phased array aspect of the process, while the array refers to the multiple elements that make up a Phased Array testing system.

The beam from a phased array probe can be electronically focused and swept across an inspection piece without moving the probe itself. This differs from single element probes (also known as monolithic probes) where these probes must be physically moved or rotated to cover larger surfaces, which is not necessary for Phased Array Testing.

Phased array ultrasonic testing is based on the principles of wave physics, which also have applications in fields such as optics and electromagnetic antennas. The Phased Array method is an ultrasonic method based on a multi-element transducer known as an array transducer. Each element can be activated individually, in groups, or all elements simultaneously or with small delays between elements.

ISO 13588 – refers to „Non-destructive testing of welds - Ultrasonic testing - Use of automated phased array technology”.

Advantages of Phased array:

- Phased Array Ultrasound Testing (PAUT) offers numerous advantages over other Non-Destructive Testing (NDT) methods, such as increased flaw detection ability and faster inspection speed;
- by using a probe to steer and control the direction and shape of the ultrasound beam, PAUT allows for more diverse surface scanning angles compared to eddy current technology. This optimized control increases coverage and detection of flaws in materials, including those with

complex geometries. Additionally, PAUT can determine material thickness changes caused by corrosion or erosion during inspection.

- PAUT also enables faster inspection speed through the use of multiple transducers in a single probe. This reduces the need for setup reconfiguration and changing of probes for each unique testing. Additionally, the digital feedback from a phased array system is received instantaneously, allowing for quicker identification of flaws and a better understanding of weld quality.

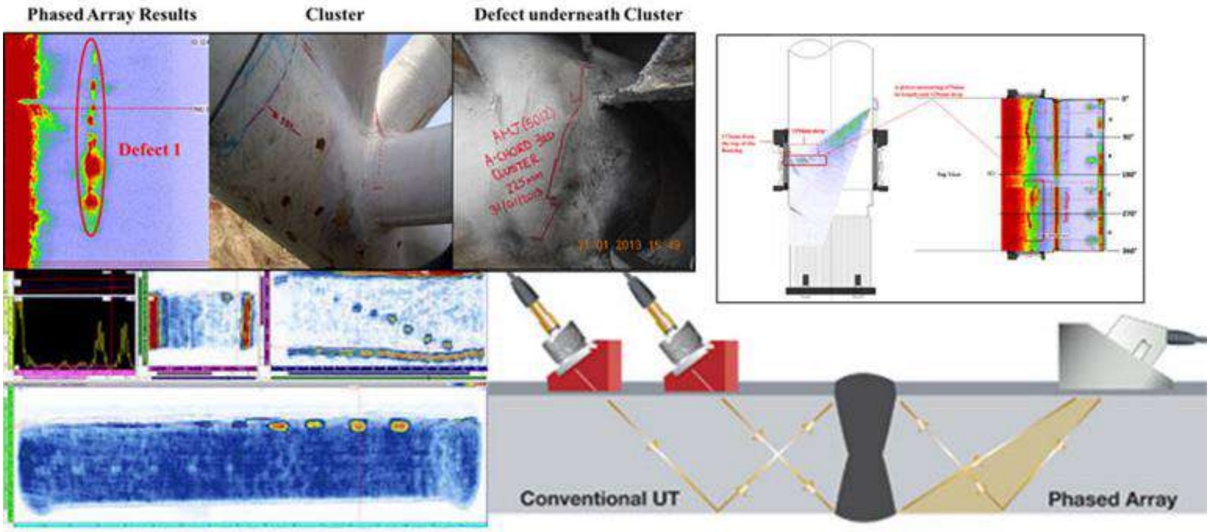


Figure 1

Disadvantages of Phased array:

- Applicability - Although Phased Array techniques have a wide range of applications, they are not the preferred method for detecting surface cracks, metal fatigue, or bolt hole inspections, as compared to eddy current testing. Eddy current testing is ideal for detecting surface flaws and inspecting tubing, while Phased Array techniques are highly effective in detecting corrosion, composite materials, and thicker welds;
- Complexity of operation - Phased Array techniques equipment is more advanced than conventional ultrasonic testing equipment, with numerous capabilities. Therefore, a trained professional should operate the equipment to eliminate the risk of inaccurate testing and to use the equipment to its full potential;
- Higher initial cost - Investing in Phased Arrays techniques equipment may have a higher initial cost than conventional ultrasonic testing systems due to its advanced features. However, Phased Array techniques' advanced capabilities can result in faster, more accurate, and efficient inspections, maximizing asset uptime. This, in turn, can lead to a lower total cost of ownership with Phased Array techniques equipment.

Principles of advanced test techniques:

The principles of Phased-array probes consist of multiple piezoelectric crystals, that can transmit or receive independently at different times. To achieve ultrasonic beam focusing, time delays are applied to the elements to create constructive interference of the wave fronts, enabling energy to be concentrated at any depth in the test specimen being inspected.

This concept is demonstrated in the principle scheme presented, where delay laws are calculated to focus the acoustic beam at a specific depth and angle. The figure 2 shows that each element emits a spherical wave at a designated time, and the combination of these wavelets results in an almost flat wave front at the specified location.

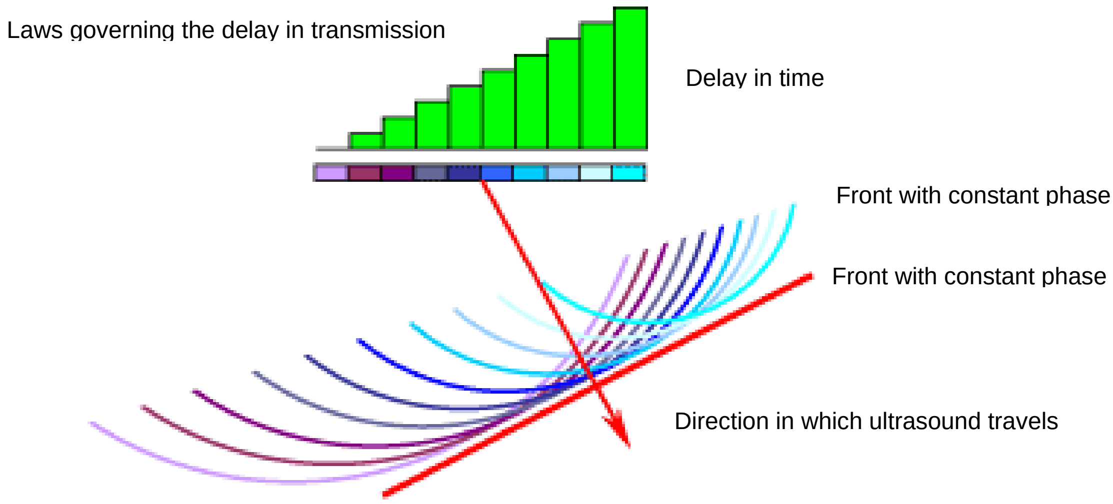


Figure 2

The figure 3, shows examples of delay-law computation, where before and after the targeted focal spot, wave fronts converge and diverge spherically. In the absence of delay laws (presented at point a), the resulting ultrasonic beam is unfocused and equivalent to the beam produced by a conventional flat transducer. The inherent "pseudo focalization" seen in the image corresponds to the near-field distance of the probe.

Example b represents the same ultrasonic beam generated by a conventional flat transducer used with a wedge, with no focusing of the ultrasonic energy. The applied delay laws result in steering of the ultrasonic beam.

Points c and d are identical to points a and b, except for the modified delay laws that focus the acoustic energy at a specified depth. In both images (c and d), the focal spot is narrower and more localized. To achieve the same results with a conventional probe, a specially designed crystal shaped to obtain the desired focal point will be required.

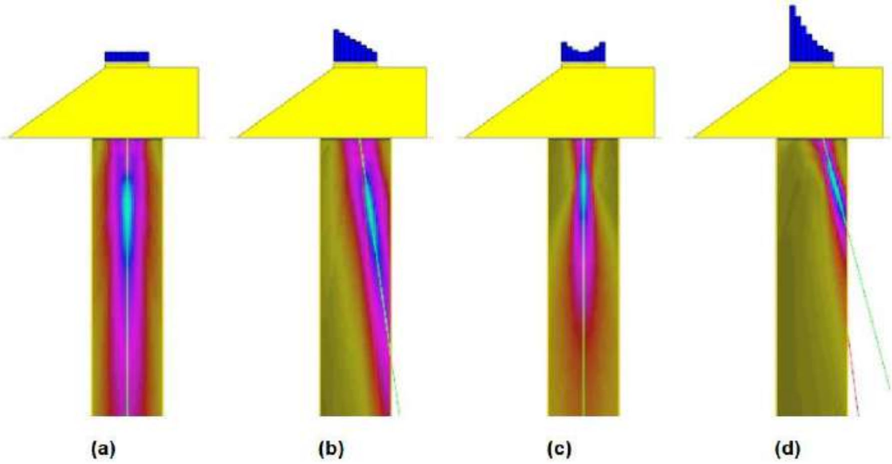


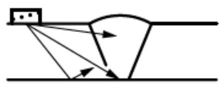
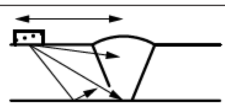
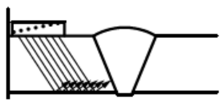
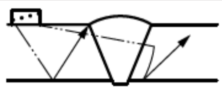
Figure 3

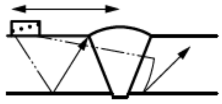
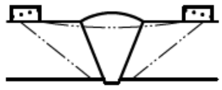
(a) no delay-laws applied, (b) steering only, (c) depth focusing and (d) combined steering and depth focusing

Description of testing level

The table 1 present the testing level's minimum requirements descriptions and examples of testing sketches.

Table 1

Mode	Testing levels			Example of sketches
	A	B	C	
	Reference blocks (see Annex A)			
	Block A	Block B	Block C	
Test set-up				
Fixed angles at fixed probe position to weld (line scans)[a]	Two sides	Not suitable as single technique	Two sides	
Fixed angles with raster scanning[a]	One side	One side	One side	
E-scan at fixed probe position (line scan)[a]	One side	Two sides with two angles [c]	Two sides	
S-scan at fixed probe position to weld (line scan)[a]	One side	Two sides or two probe positions	Two sides or two probe positions	

Mode	Testing levels			Example of sketches
	A	B	C	
	Reference blocks (see Annex A)			
	Block A	Block B	Block C	
S-scan raster	Not recommended		One side	
TOFD generated with phased array[a]	Not recommended, TOFD testing in accordance with ISO 10863		One setup	
Skewed scan[b]	If required by specification			

[a] For testing level C, at least two different test setups from this table shall be combined; at least one of them shall be S-scan or TOFD.

[b] If detection of transverse discontinuities is required by specification, a suitable additional test setup shall be applied. Skewed probe or electronically skewed beam can be used.

[c] At least 10° difference between angles.

In order to calibrate your equipment, you need to use a reference block, it must be used to verify the setup. When scanning from one side (excluding using TOFD), both half and full skip must be utilized and stored. However, if scanning is performed from both faces, half skip is adequate. If diffraction signals are detected, they can be utilized for sizing purposes. If the assessment of discontinuities is solely based on amplitude, the beam direction's deviation from the normal to the weld bevel cannot exceed 6°. In cases where this is not possible due to the test object's geometry (for e.g., weld cap, narrow gap weld), the scan plan should outline the corrective actions and describe how these areas will be tested with enough sensitivity.

Items to be defined prior to procedure development

In order to develop the testing procedure, certain items need to be defined beforehand. This includes information on:

a) purpose and extent of testing;
b) test levels;
c) acceptance criteria;
d) specification of reference blocks;
e) manufacturing or operation stage at which the testing is to be carried out;
f) weld details and information on the size of the heat-affected zone;
g) requirements for access and surface conditions and temperature;
h) personnel qualification;
i) reporting requirements.

Written test procedure

A written test procedure is necessary for all testing levels. It procedure should contain the following information at minimum:

a) purpose and extent of testing;
b) testing techniques;
c) testing levels;
d) personnel qualification/training requirements;
e) equipment requirements (including but not limited to frequency, sampling rate, pitch between elements, element size);
f) reference and/or test blocks;
g) setting of equipment;
h) available access and surface conditions;
i) testing of parent material;
j) evaluation of indications;
k) acceptance levels and/or recording levels;
l) reporting requirements;
m) environmental and safety issues.

Personnel qualifications

- Personnel performing testing shall be qualified to an appropriate level in accordance with ISO 9712 or equivalent in the relevant industrial sector.
- In addition to general knowledge of ultrasonic weld testing, the operators shall be familiar with, and have practical experience in, the use of ultrasonic phased arrays. Specific training and examination of personnel should be performed on representative pieces. These training and examination results should be documented. If this is not the case, specific training and examination should be performed with the finalized ultrasonic testing procedures and selected ultrasonic test equipment on representative samples containing natural or artificial reflectors similar to those expected. These training and examination results should be documented.

Test equipment

Information regarding Test equipment can be found in standard ISO/TS 16829 that provides valuable guidance on the selection of system components, including both hardware and software. When applicable, the ultrasonic equipment employed for phased array testing must meet the specifications of ISO 18563-1, ISO 18563-2, and ISO 18563-3.

An Ultrasonic instrument will ensure the A-scans are digitized accurately, the instrument should have the capability to choose a suitable section of the time base. It is advisable to use a minimum A-scan sampling rate of six times the nominal probe frequency.

The Ultrasonic probes which generate Longitudinal and shear waves are both viable options. When adapting probes to curved scanning surfaces, adherence to ISO 17640 is necessary. Any impact on the sound beam due to the use of adapted probes should be considered.

The maximum number of dead elements on each active aperture should not exceed 1 out of 16, and there should be no adjacent dead elements. If active apertures utilize fewer than 16 elements, there should be no dead element, unless satisfactory performance can be proven.

The Scanning mechanism needs to ensure image consistency (for example for the collected data), and it is necessary to employ the guiding mechanisms and scan the encoder or encoders.

Preparation for testing

At this stage, will be taken into account the following:

- The volume to be tested: where the testing's objective must be specified according to the relevant standards. Subsequently, the testing volume must be determined. During manufacturing tests, the testing volume should cover the weld and the base material on each side of the weld, for at least 10 mm (5 mm for laser and electron beam welds) or the width of the heat-affected zone (based on manufacturer information), whichever is greater. A scan plan should be included, showing the beam coverage, weld thickness, and weld geometry. It is crucial to ensure that the sound beams covers the testing volume thoroughly.

- Verification of the test setup: Reference blocks must be used to verify the capability of the test setup.

- Scan increment setting: The scan increment along the weld must be adjusted according to the wall thickness to be tested. For thicknesses up to 10 mm, the scan increment should not exceed 1 mm. For thicknesses ranging between 10 mm and 150 mm, the scan increment should be no more than 2 mm. When thicknesses exceed 150 mm, it is recommended that a scan increment of no more than 3 mm be utilized. The scan increment along the weld perpendicular to the test section must be determined to ensure complete test volume coverage. In the event of TOFD, the scan increment must comply with the guidelines specified in ISO 10863.

- Geometry considerations: Testing of welds with complex geometry, such as those joining materials of varying thickness, or those that are angled or nozzles, requires careful planning and thorough understanding of sound propagation. Such tests must be conducted at testing level D, unless single-sided testing is permitted. For level D tests, it is mandatory to have scan plan(s), representative reference block(s), and a performance demonstration.

- Preparation of scanning surfaces: To fully cover the test volume, the scanning surfaces must be clean and wide enough. Any foreign matter that could interfere with probe coupling, such as rust, loose scale, weld spatter, notches, or grooves, must be removed to ensure even surfaces. If the test surface has waviness, it must not create a gap between the probe and test surface greater than 0.5mm. Preparing the scanning surface is necessary to meet these requirements. For machined surfaces, the surface roughness Ra must not be greater than 6.3 micro meter, while for shot-blasted surfaces, it must not be greater than 12.5 micro meter. If a layer of different material, such as a coating, paint, or cladding, is present on the scanning surface and cannot be removed, testing level D should be applied.

- Temperature - If special high-temperature phased array probes and couplants are not being used, the surface temperature of the object being tested must be within the 0°C to 50°C range. For temperatures outside of this range, the testing equipment's suitability must be confirmed.

- Couplant - To produce accurate images, it's necessary to use a couplant that maintains a consistent transmission of ultrasound between the probes and the object being tested. The same couplant utilized during calibration must also be used during subsequent testing and post-calibration.

Preparation for testing. Verification of the test setup

The capability of the test setup shall be verified by the use of reference blocks. The use of reference blocks is required to assess the effectiveness of testing based on the designated testing level, including coverage and sensitivity setting. Figure 4, 5, and 6 provide recommended reference block options.

The reference block's material must be comparable to the test object, taking into account factors such as sound velocity, grain structure, and surface condition.

To ensure accurate testing, the reference block's thickness should ideally be between 0.8 to 1.5 times the thickness of the test object, with a maximum difference of 20 mm compared to the test object. The length and width of the reference block must be selected to allow for proper scanning of all artificial discontinuities. When testing longitudinal welds in cylindrical test objects, curved reference blocks with diameters between 0.9 to 1.5 times the test object diameter are recommended. For test objects with a diameter of 300 mm or greater, a flat reference block may be used.

The diameter or curvature of the reference block must conform to ISO 17640. The maximum gap allowed between the probe shoe and reference block is 0.5 mm.

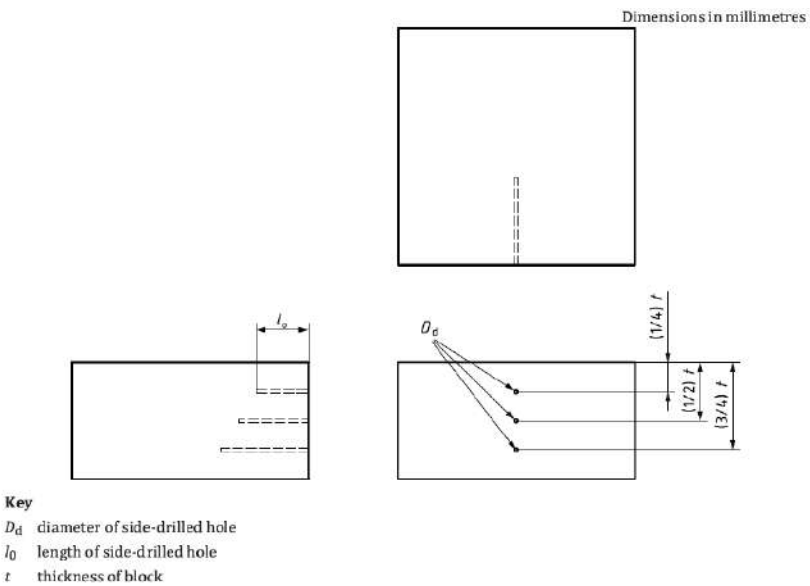
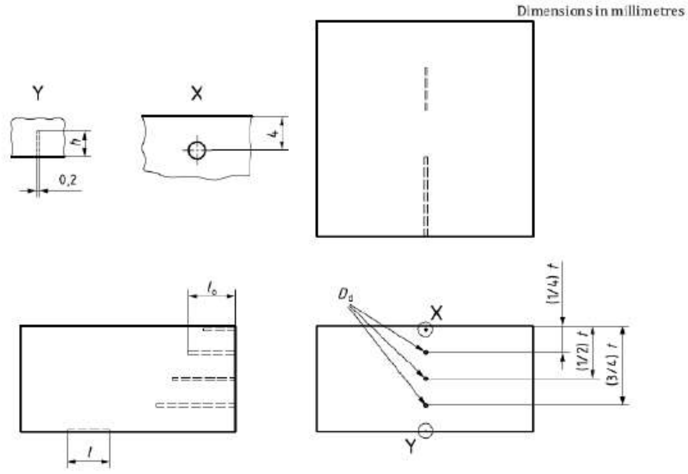


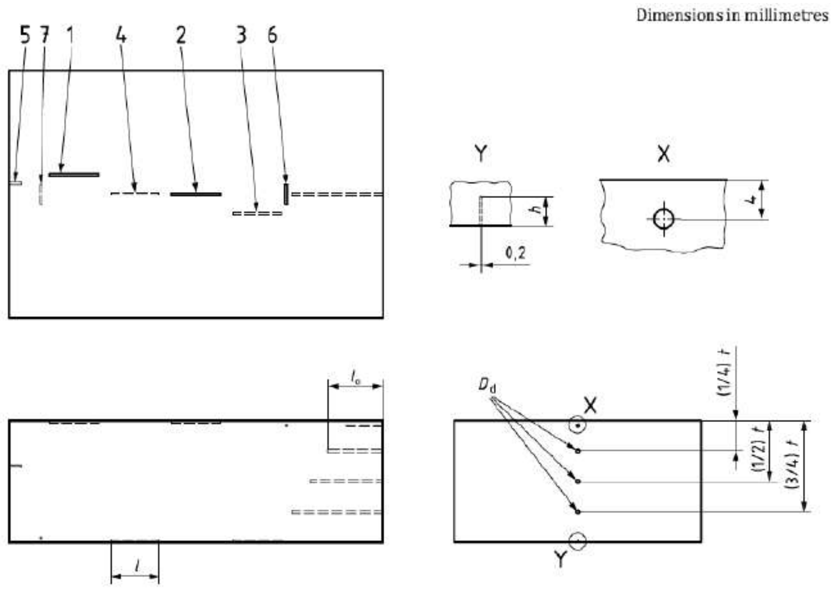
Figure 4 - Recommended reference block for testing level A



Key

D_d diameter of side-drilled hole
h depth of notch at the bottom
l length of notch
l_0 length of side-drilled hole
t thickness of block

Figure 5 - Recommended reference block for testing level B



Key

D_d diameter of side-drilled hole
h depth of the notch at the bottom
l length of notch
l_0 length of side-drilled hole
t thickness of block

1, 2 near-side surface notches
3, 4 far-side surface notches
5 notch on imaginary weld bevel
If required by specification:
6 near-side surface transverse notch
7 far-side surface transverse notch

Figure 6 - Recommended reference block for testing level C

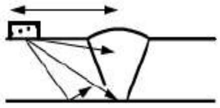
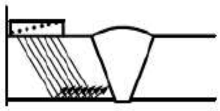
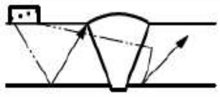
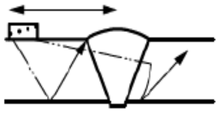
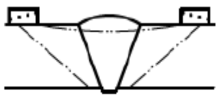
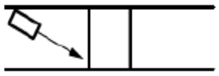
Testing level	Reference block
A	Figure 4
B	Figure 5
C	Figure 6
D	As specified

Preparation for testing. Geometry considerations

Testing of welds with complex geometry, such as those joining materials of varying thickness, or those that are angled or nozzles, requires careful planning and thorough understanding of sound propagation. Such tests must be conducted at testing level D, unless single-sided testing is permitted. For level D tests, it is mandatory to have a scan plan or plans, representative reference block or blocks, as well as a performance demonstration, as detailed in the previous slide (Reference blocks).

Note: that simulation programs may be used to reduce the number of required reference blocks in some cases.

Table 2

Mode	Testing levels			Example of sketches
	A	B	C	
	Reference blocks (see Annex A)			
	Block A	Block B	Block C	
Test set-up				
Fixed angles at fixed probe position to weld (line scans)[a]	Two sides	Not suitable as single technique	Two sides	
Fixed angles with raster scanning[a]	One side	One side	One side	
E-scan at fixed probe position (line scan)[a]	One side	Two sides with two angles [c]	Two sides	
S-scan at fixed probe position to weld (line scan)[a]	One side	Two sides or two probe positions	Two sides or two probe positions	
S-scan raster	Not recommended		One side	
TOFD generated with phased array[a]	Not recommended, TOFD testing in accordance with ISO 10863		One setup	
Skewed scan[b]	If required by specification			

[a] For testing level C, at least two different test setups from this table shall be combined; at least one of them shall be S-scan or TOFD.

[b] If detection of transverse discontinuities is required by specification, a suitable additional test setup shall be applied. Skewed probe or electronically skewed beam can be used.

[c] At least 10° difference between angles.

Testing of base material and Range and sensitivity settings

For the settings of the range and sensitivity, must be established before each test in compliance with the guidelines outlined in this e-course. Any adjustments to the phased array setup, such as changes to probe position (PP) or steering parameters, necessitates a new setup.

To achieve optimal results, the signal-to-noise ratio should be optimized with a minimum of 12 decibels for reference signals when utilizing A-scans, or with a minimum of 6 decibels when using phased-array images.

At this stage, the following will be taken into account:

- In cases where it applies, the pulse-echo time window must encompass the region of interest and be documented in the written test procedure. It's important to verify that the combination of beams covers the area of concern.

- Upon selecting the mode (fixed angle, E-scan, S-scan), the pulse-echo sensitivity settings should be established by:

a) determining the test sensitivity for every generated beam (for example the beam angle or the focal point) using the phased array probe;
b) when utilizing a wedge with the probe, setting the sensitivity with the wedge in position.

Phased array probes can utilize various modes of focusing, such as static and dynamic depth focusing (DDF). If focusing is implemented, the sensitivity must be established for every focused beam. By utilizing angle-corrected gain (ACG) and time-corrected gain (TCG), signals for all beam angles and distances can be displayed with uniform amplitude.

Phased array testing for welds can be performed in various modes such as fixed angles, E-scans, and S-scans. After completing the previous steps, the reference sensitivity for each beam generated must be set in accordance with ISO 17640, which includes transfer correction if necessary.

- All settings used for Time of Flight Diffraction (TOFD) testing shall conform to the specifications outlined in ISO 10863.
- The settings shall undergo a verification process every 4 hours and after the conclusion of the testing. If a single test exceeds 4 hours, the settings shall be verified once the test is finished.

If a reference block was utilized for the initial setup, it is mandatory to use the same reference block for the checking process. Alternatively, a smaller block with known transfer properties may be used. If any deviations are detected from the initial settings during these checks, the corresponding corrections, specified in the presented Table, must be carried out.

Weld testing

Prior to conducting initial testing, the scan plan must be verified to ensure coverage and demonstrated on an appropriate reference block. Any acceptable deviations in probe positioning relative to the weld centreline must be recorded in the test procedure and accounted for in the scan plan and reference block.

If certain discontinuities are detected during the initial scan, additional evaluation such as offset scans, scans perpendicular to the discontinuity, or complementary phased array setups may be necessary. The scanning speed should be selected in a way that produces satisfactory images, taking into consideration factors such as number of delay laws, scan resolution, signal averaging, pulse-repetition frequency, data acquisition frequency, and volume to be tested. Missing scan lines indicate that the scanning speed was too high, and a maximum of 5% of the total number of lines collected in one single scan may be missed, but no adjacent lines should be missed.

If a weld is scanned in multiple sections, an overlap of at least 20 mm between adjacent scans is required. The same overlap is necessary for the end of the last scan and the start of the first scan when scanning circumferential welds. If appropriate, a control function for the coupling efficiency is recommended.

Interpretation and analysis of phased array data

Interpretation and analysis of phased array data are typically performed as follows:

a) assess the quality of the phased array data. A phased array test shall be carried out such that satisfactory images are generated which can be evaluated with confidence. Satisfactory images are defined by appropriate:
   1) coupling;
   2) time-base setting;
   3) sensitivity setting;
   4) signal-to-noise ratio;
   5) indication of saturation;
   6) data acquisition.

Assessing the quality of phased array images requires skilled and experienced operators. The operator shall decide whether non-satisfactory images require new data acquisition (re-scanning).

b) identify relevant indications. The phased array technique images both discontinuities in the weld and geometric features of the test object. In order to distinguish between indications and geometric features, detailed knowledge of the test object is necessary.

To decide whether an indication is relevant (caused by a discontinuity), patterns or disturbances in the phased array images, shall be evaluated considering shape and signal amplitude relative to general noise level.

c) classify relevant discontinuities as specified; Amplitude, location and pattern of relevant indications can contain information on the type of the discontinuity. Relevant indications shall be classified as specified.
d) determine location and size of the discontinuities as specified;

The location of a discontinuity parallel to the weld axis, perpendicular to the weld axis and in the through-wall direction shall be determined from the related indication.

The length and height of a discontinuity are determined by the length and height of its indication. The length is defined by the difference of the x-coordinates of the indication. The length of an indication shall be measured as described in ISO 11666. If TOFD is used the length of an indication shall be measured as described in ISO 15626. Alternative techniques for measuring indication length may be used when specified. The height is defined as the maximum difference of the z-coordinates. For indications displaying varying height along their length, the height shall be determined at the scan position of maximum extent, presented in figure 4 and 5.

e) evaluate the data against acceptance criteria.

Test report

The test report shall include at least the following information:

a) reference to this document, for example ISO 13588;

b) information relating to the object under test, namely:
1) identification of the test object;
2) dimensions including wall thickness;
3) material type and product form;
4) geometrical configuration;
5) location of the tested welded joint(s);
6) reference to welding process and heat treatment;
7) surface condition and temperature of the test object;
8) stage of manufacture of the test object;

c) information relating to the test equipment, namely:
1) manufacturer and type of the phased array instrument including scanning mechanisms with identification numbers if required;
2) manufacturer, type, frequency of the phased array probes including number and size of elements, material and angle(s) of wedges with identification numbers if required;
3) details of the reference block(s) with identification numbers if required;
4) type of couplant used;

d) information relating to the test technology, like the following:

1) testing level and reference to a written test procedure;
2) purpose and extent of test;
3) details of datum and coordinate systems;
4) method and values used for range and sensitivity settings;
5) details of signal processing and scan increment setting;
6) scan plan;
7) access limitations and deviations from this document; if any;

e) information relating to the phased array setting, namely:

1) increment (E-scans) or angular increment (S-scans);
2) element pitch and gap dimensions;
3) focus (calibration should be the same as for scanning);
4) virtual aperture size, for example number of elements and element width;
5) element numbers used for focal laws;
6) maximum deviation of the beam direction from the normal to the weld bevel;
7) documentation on permitted wedge angular range, specified by the manufacturer;
8) documented calibration, time-corrected gain (TCG) and angle-corrected gain (ACG);

f) information relating to the test results, like:

1) reference to the phased array raw data file(s),
2) phased array images of at least those locations where relevant discontinuities have been detected on hard copy, all images or data available in soft format;
3) acceptance criteria applied;
4) tabulated data recording the classification, location and size of relevant discontinuities and the results of evaluation;
5) reference points and details of the coordinate system;
6) date of test;
7) names, signatures and qualification of the test personnel.

Equipment

The phased ultrasonic detector has extensive application in various fields such as manufacturing, steel metallurgy, metal processing, chemical industry, etc., where defect detection and quality control are critical. It is also a common tool for operational safety inspection and life assessment in the aerospace industry, railway transportation, pressure vessel of boilers, and other related areas. Hence, it is considered an indispensable tool for the non-destructive testing industry.

Phased array ultrasonic testing presents numerous advantages and can be applied across a diverse range of industries and applications. As a non-destructive testing technique, it surpasses many other methods, such as X-ray testing, in terms of reliability, efficiency, and speed.

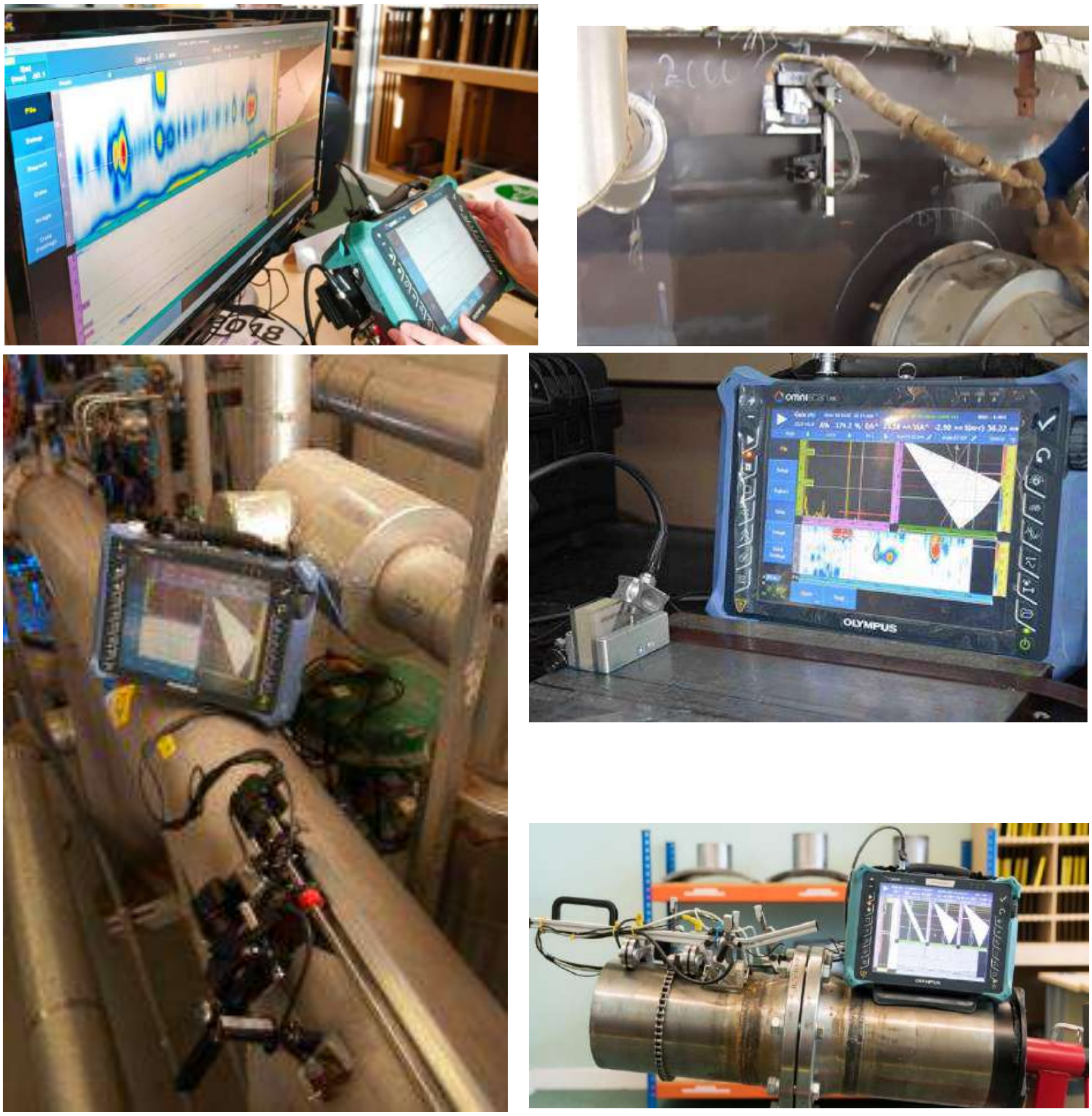


Figure 7 - Phase array equipments

2.8.2. Time of Flight Diffraction (TOFD)

The Time-of-flight diffraction (TOFD) method is a highly precise and sensitive technique utilized for the non-destructive testing of welds to identify defects. The technique originated from tip diffraction methodologies that were first introduced by Silk and Liddington in 1975, which led to the development of TOFD. Further studies on this technique have been documented in several sources, including Harumi and company in1989), Avioli and company in1991), and Bray and Stanley in 1997.

Bray and Stanley (in 1997) characterized TOFD as a tip-diffraction technique that leverages the principle that the tips of a crack, when struck by a wave, diffract the signals back to another location on the surface. The depth of these tips can be accurately determined based on the diffracted energy.

Initially, TOFD was invented as a research tool in the UK in the 1970s. The use of TOFD has enabled more accurate measurement of crack sizes, enabling expensive components to be kept in operation for as long as possible with minimal risk of failure.

ISO 10863 – refers to „Non-destructive testing of welds - Ultrasonic testing - Use of time-off-light diffraction technique (TOFD)".

Advantages of TOFD

- The use of ultrasonic diffraction has unique benefits in accurately sizing crack-like planar defects. During a TOFD inspection, waves originating at the crack tips are diffracted, and the difference in time of flight of these waves provides information on the extent of the crack.
- TOFD is a single pass operation that is not dependent on amplitude and is very accurate in sizing vertical defects.
- The technique is substantially more accurate in sizing the height of defects than conventional pulse echo techniques, which rely on echo amplitude.
- TOFD is popular due to its high probability of detection, low false call rate, portability, and intrinsic accuracy in flaw sizing, particularly in depth.
- It provides a quick visual representation of the cross section of the weld, similar to RT film, allowing for a rapid preliminary analysis of the material/weld condition. It is easier to show clients than phased array data, which displays everything in one strip chart.
- TOFD detects all indications, regardless of orientation, and is also effective in identifying volumetric indications that phased array or pulse echo ultrasonic may miss due to signal scattering or absorption.
- TOFD scanning can be performed quickly, and the resulting data files are compact.
- TOFD does not add significant complexity to phased array inspections but can enhance sizing accuracy.

Disadvantages of TOFD

- Sensitivity level: If the instrument's sensitivity (the gain) is set too low, the TOFD image will not display any diffracted echo. Conversely, if the sensitivity is set just above the electronic noise level, the image will show numerous diffracted echoes caused by very small deviations of the weld seam, which may not necessarily indicate a poor weld quality.
- TOFD requires a very high gain, which generates a significant back wall echo, making it unsuitable for coarse-grained materials.
- There is a dead zone for defect detection beneath the surface. As a result, defects located near the surface may not be detected, but this can be overcome by using Magnetic Particle Test (MPT) or testing with a creeping wave probe.

- The minimum thickness requirement for TOFD is 6mm with a diameter of 4mm. However, there is no maximum thickness limitation, and it can be several hundred millimeters.
- TOFD cannot be used on coarse-grain weldments such as austenitic stainless steel and Inconel.

TOFD Principles

Relying on the amplitude of reflected signals is a relatively unreliable approach to sizing defects because the amplitude heavily relies on the orientation of the crack. In contrast, TOFD determines the position and size of a reflector using the time of flight of an ultrasonic pulse.

In a TOFD system, two ultrasonic probes are placed on opposite sides of a weld. One probe, called the transmitter, emits an ultrasonic pulse that is received by the probe on the other side, the receiver. In undamaged pipes, the receiver probe detects two waves: one traveling along the surface and one reflecting off the far wall. However, in the presence of a crack, the ultrasonic wave diffracts from the tip or tips of the crack. By measuring the time of flight of the pulse, the depth of the crack tips can be automatically calculated using simple trigonometry.

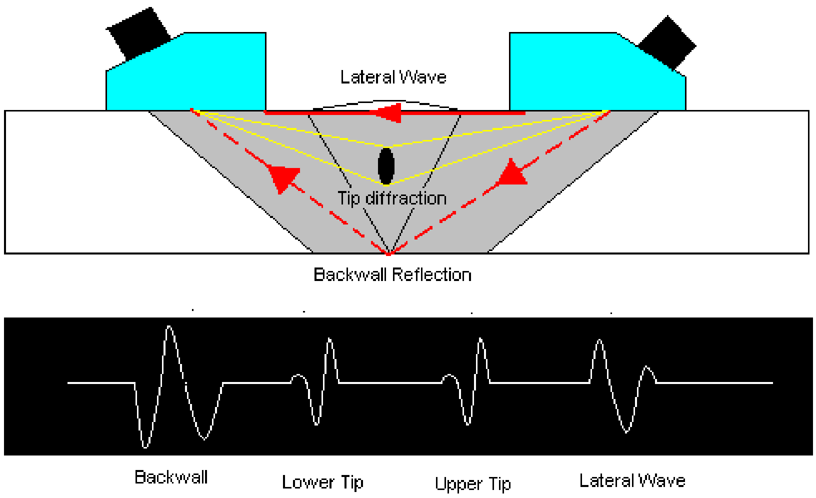


Figure 8

TOFD can be used independently or in conjunction with other ultrasonic techniques. Some of the most common techniques are:

- Single group TOFD;
- Multiple TOFD;
- TOFD with pulse echo/creeping waves;
- TOFD with phased array.

The Main Benefits of TOFD for Weld Inspection are:

- Based on diffraction, so relatively indifferent to weld bevel angles and flaw orientation;
- Uses time of arrival of signals received from crack tips for accurate defect positioning and sizing;

- Precise sizing capability makes it an ideal flaw monitoring method;
- Quick to set up and perform an inspection, as a single beam offers a large area of coverage;
- Rapid scanning with imaging and full data recording;
- It Can also be used for corrosion inspections;
- Required equipment is more economical than phased array, due to conventional nature (single pulsar and receiver) and use of conventional probes;
- Highly sensitive to all weld flaw types.

ISO 16828 provides general principles of the TOFD technique, but for testing fusion-welded joints, specific capabilities and limitations should be considered. TOFD generates ultrasonic images that can detect, locate, and size discontinuities in the weld and adjacent parent materials. Unlike reflection-based techniques, TOFD is less sensitive to the orientation of the discontinuity, detecting those oriented perpendicular to the surface and at intermediate angles. In certain circumstances, more than one TOFD setup is required. A typical TOFD image is linear in time and probe movement, but the V-configuration of the ultrasound paths makes the location of a possible discontinuity non-linear. To ensure valid images, coupling losses and data acquisition errors should be avoided, and skilled operators are required for interpretation. The capability to detect discontinuities close to or connected with the scanning surface or opposite surface is reduced, especially for crack-sensitive steels or in-service inspections, requiring additional measures like other NDT methods or techniques. In coarse-grained material, diffracted signals from weld discontinuities can have small amplitude responses that may be hindered by grain scatter effect, which should be considered when testing such material.

County Testing level

Table 3, specifies four testing levels (A, B, C, and D), with increasing reliability from testing level A to C. If setup parameters do not comply with Table 4, the capability must be verified using reference blocks. If the specified acceptance level requires the detection of a certain discontinuity size at both surfaces or one surface of the weld, it may require the use of techniques or methods outside the scope of this document.

For manufacturing inspections (refer to ISO 17635), all testing levels are applicable, but Level A is only applicable for wall thicknesses up to 50 mm. For in-service inspections, only testing level D should be applied.

For testing levels A and B, it is recommended to verify the TOFD setup using reference blocks. For testing levels C and D, all setups chosen for the test object should be verified using reference blocks.

Table 3

Testing level	TOFD setup	Reference block for setup verification	Reference block for sensitivity settings	Offset scan	Written test procedure
A	As in Table 2	No	No	No	This document
B	As in Table 2	No	Yes	No	This document
C	As in Table 2	Yes	Yes	a	Yes
D	As defined by specification	Yes	Yes	a	Yes

[a] The necessity, number and position of offset scans shall be determined.

Table 4

Thickness t mm	Number of TOFD setups	Depth range Δt mm	Centre frequency f MHz	Beam angle (longitudinal waves) α °	Transducer size mm	Beam intersection
6 to 10	1	0 to t	15	70	2 to 3	2/3 of t
>10 to 15	1	0 to t	15 to 10	70	2 to 3	2/3 of t
>15 to 35	1	0 to t	10 to 5	70 to 60	2 to 6	2/3 of t
>35 to 50	1	0 to t	5 to 3	70 to 60	3 to 6	2/3 of t
>50 to 100	2	0 to $t/2$	5 to 3	70 to 60	3 to 6	2/6 of t
		$t/2$ to t	5 to 3	60 to 45	6 to 12	5/6 of t
>100 to 200	3	0 to $t/3$	5 to 3	70 to 60	3 to 6	2/9 of t
		$t/3$ to $2t/3$	5 to 3	60 to 45	6 to 12	5/9 of t
		$2t/3$ to t	5 to 2	60 to 45	6 to 20	8/9 of t
>200 to 300	4	0 to $t/4$	5 to 3	70 to 60	3 to 6	2/12 of t
		$t/4$ to $t/2$	5 to 3	60 to 45	6 to 12	5/12 of t
		$t/2$ to $3t/4$	5 to 2	60 to 45	6 to 20	8/12 of t
		$3t/4$ to t	3 to 1	50 to 40	10 to 20	11/12 of t; or t for $\alpha \leq 45°$

Information required prior to testing. Items to be defined prior by specification

Information on the following items is required in case of TOFD inspection:

a) purpose and extent of TOFD testing;

b) testing levels, e.g.;

1) whether a written test procedure is required;
2) whether reference blocks are required;

c) specification of reference blocks, if required;

d) manufacturing or operation stage at which the testing is to be carried out;

e) requirements for: temperature, access and surface conditions;

f) reporting requirements;

g) acceptance criteria;

h) personnel qualifications.

Specific information required by the operator before testing

Before any testing of a welded joint can begin, the operator shall have access to all the information as specified in previously slide together with the following additional information:

a) written test instruction or procedure, if required;
b) Type or types of base materials and product form (for example, cast, forged, rolled);
c) joint preparation and dimensions;
d) welding procedure or relevant information on the welding process;
e) time of testing relative to any post-weld heat treatment;
f) result of any base metal testing carried out prior to and or after welding;
g) discontinuity type and morphology to be detected.

Written test instruction or procedure

For testing levels, A and B, is necessary one written test procedure.

For testing levels C and D, or where the techniques described in this document are not applicable to the welded joint to be tested, a specific written test procedure shall be used.

When data collection is performed by personnel qualified to Level 1 according to ISO 9712, a written test instruction shall be prepared.

Personnel qualifications

All personnel involved in ultrasonic weld testing must possess both a general understanding of the method and competence in the TOFD technique. Documentation of their competency, including their level of training and experience, is required.

For the preparation of written test instructions, final offline analysis of data, and acceptance of the report, personnel qualified at a minimum to Level 2, in accordance with ISO 9712 or, its equivalent in ultrasonic testing within the relevant industrial sector must perform these tasks. However, with written instruction and under the supervision of Level 2 or Level 3 personnel, personnel qualified at a minimum to Level 1, in accordance with ISO 9712 or its equivalent in ultrasonic testing within the relevant industrial sector can carry out equipment setup, data acquisition, data storage, and report preparation. During data acquisition, Level 1 personnel, may be assisted by a technician. If the aforementioned minimum qualifications are deemed insufficient, job-specific training must be provided.

Test equipment

The TOFD software shall not mask any problems such as loss of coupling, missing scan lines, synchronization errors or electronic noise.

- Ultrasonic instrument

The ultrasonic instrument used for the TOFD technique shall comply with the requirements of ISO 22232-1, where applicable.

- Ultrasonci probes

Probes used for the TOFD technique on welds shall comply with ISO 22232-2 and ISO 16828.

- Scanning mechanisms

The requirements of ISO 16828 shall apply. To achieve consistency of the images (collected data), guiding mechanisms may be used.

Preparation for testing

In preparation for testing, the following factors must be considered:

a) Determination of volume to be tested: The volume to be tested is determined based on the purpose of the testing, as specified in ISO 16828. For manufacturing inspection, the volume to be tested includes the weld and base material for at least 10 mm on each side of the weld or the width of the heat-affected zone, whichever is greater. For in-service inspections, the volume to be tested may be targeted to specific areas of interest, and the acceptance criteria and minimum discontinuity size shall be specified.

b) Setup of probes: The probes must be set up to ensure adequate coverage and optimum conditions for the initiation and detection of diffracted signals in the area of interest. Reference blocks should be used to verify the effectiveness and coverage of the setup. The selection of probes for full coverage of the complete weld thickness should follow appropriate combinations of parameters. For testing levels A and B, the TOFD setup should be verified by reference blocks, while for testing levels C and D, all the setups chosen for the test object shall be verified by reference blocks.

c) Scan increment setting: The scan increment setting should be determined based on the wall thickness to be tested, with a scan increment of no more than 0.5 mm for thicknesses up to 10 mm, 1 mm for thicknesses between 10 mm and 150 mm, and 2 mm for thicknesses above 150 mm.

d) Geometry considerations: Welds of complex geometry require special attention, and additional scans may be necessary to overcome obscured areas of interest. Planning testing of complex geometries requires in-depth knowledge of sound propagation, representative reference blocks, and sophisticated software.

e) Preparation of scanning surfaces: Scanning surfaces should be wide enough to permit full coverage of the volume to be tested and even, free from foreign matter likely to interfere with probe coupling. Waviness of the test surface shall not result in a gap between one of the probes and the test surface greater than 0.5 mm, and any required dressing should be done to ensure this.

f) Temperature: When using conventional probes and couplants, the surface temperature of the test object should be in the range of 0°C to 50°C. For temperatures outside this range, the suitability of the equipment should be verified.

g) Couplant: A couplant providing constant transmission of ultrasound between the probes and the test object is required to generate proper images. The couplant used for calibration should be the same as that used in subsequent testing and post-calibrations.

h) Provision of datum points: A permanent reference system should be applied to ensure repeatability of the testing.

Table 5

Thickness t mm	Number of TOFD setups	Depth range Δt mm	Centre frequency f MHz	Beam angle (longitudinal waves) α °	Transducer size mm	Beam intersection
6 to 10	1	0 to t	15	70	2 to 3	2/3 of t
>10 to 15	1	0 to t	15 to 10	70	2 to 3	2/3 of t
>15 to 35	1	0 to t	10 to 5	70 to 60	2 to 6	2/3 of t
>35 to 50	1	0 to t	5 to 3	70 to 60	3 to 6	2/3 of t
>50 to 100	2	0 to $t/2$	5 to 3	70 to 60	3 to 6	2/6 of t
		$t/2$ to t	5 to 3	60 to 45	6 to 12	5/6 of t
>100 to 200	3	0 to $t/3$	5 to 3	70 to 60	3 to 6	2/9 of t
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>200 to 300	4	0 to $t/4$	5 to 3	70 to 60	3 to 6	2/12 of t
		$t/4$ to $t/2$	5 to 3	60 to 45	6 to 12	5/12 of t
		$t/2$ to $3t/4$	5 to 2	60 to 45	6 to 20	8/12 of t
		$3t/4$ to t	3 to 1	50 to 40	10 to 20	11/12 of t; or t for $\alpha \leq 45°$

Testing of base material

Normally, the base material doesn't need to be tested for laminations using straight beam probes prior to TOFD weld testing, as they can be detected during the testing process. However, the presence of discontinuities in the base material near the weld may result in obscured areas or difficulties in interpreting the data.

Range and sensitivity settings

Before each TOFD weld testing, range and sensitivity settings, should be set in accordance with the document and ISO 16828. Any change in the TOFD setup, such as the probe center separation (PCS), necessitates a new setting. Signal averaging can help minimize noise.

Table 6

Sensitivity	
Deviations ≤6 dB	No action required; data may be corrected by software
Deviations >6 dB	Settings shall be corrected and all tests carried out since the last valid check shall be repeated
Range	
Deviations ≤0,5 mm or 2 % of depth range, whichever is greater	No action required
Deviations >0,5 mm or 2 % of depth range, whichever is greater	Settings shall be corrected and all tests carried out since the last valid check shall be repeated

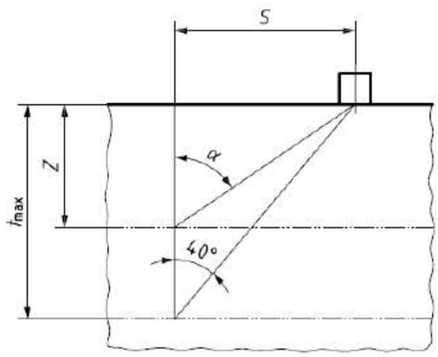
- For full-thickness testing using only one setup, the time window should start at least 1 microsecond, before the arrival of the lateral wave, and extend beyond the first mode-converted back-wall signal, if possible. When using more than one setup, the time windows should overlap by at least 10% of the depth range. The test object should verify the start and extent of the time windows.
- The lateral wave signal and the back-wall signal with the known material velocity should be used to set the time-to-depth conversion for a given PCS. This setting should be verified by a suitable block of known thickness (accuracy 0.05 mm), and at least one depth measurement should be performed in the depth range of interest, typically by recording a minimum of 20 A-scans. The measured thickness or depth should be within 0.2 mm of the actual or known thickness or depth. Geometrical corrections may be necessary for curved components.
- For all testing levels, sensitivity should be set on the test object. The amplitude of the lateral wave should be between 40% and 80% of full screen height (FSH). If the lateral wave is not appropriate, sensitivity should be set so that the amplitude of the back-wall signal is between 18 decibels and 30 decibels above FSH. When neither the lateral wave nor the back-wall signal is appropriate, sensitivity should be set so that the material grain noise is between 5% and 10% of FSH. For testing levels B, C, and D, the sensitivity should be verified by the use of test blocks to detect real discontinuities in the respective depth zone, or by using machined discontinuities (e.g. notches, side-drilled holes) if test blocks are not available.
- Checks to confirm the range and sensitivity settings should be performed at least every 4 hours and after completing the testing, as well as whenever a system parameter is changed or, changes in equivalent settings are suspected. If a reference block was used for the initial setup, the same reference block should be used for subsequent checks. Alternatively, a smaller block with known transfer properties may be used, provided that it is cross-referenced to the initial reference block. If a test object was used for checking instead of a reference block, subsequent checks should be carried out at the same location as the initial check. Corrections given in the table should be made

if deviations from the initial settings, are found in Time-to-depth conversion and Sensitivity settings during these checks.

Reference blocks

In order to evaluate the sufficiency of testing, such as coverage and sensitivity setting, a reference block should be employed, which varies depending on the level of testing. Annex A of ISO 10863 provides recommendations regarding reference blocks.

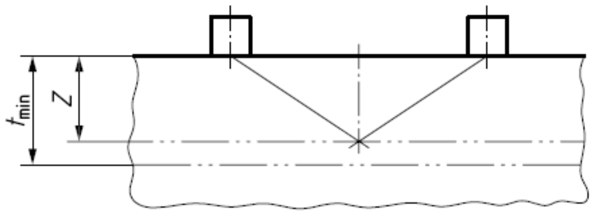
- For the reference block, it is recommended that a similar material is utilized as the test object, taking into account factors like sound velocity, grain structure, and surface condition.
- To ensure accuracy, the thickness of the reference block must be representative of the test object, falling within a minimum and maximum range in relation to the test object's thickness. Specifically, the recommended thickness for reference blocks is between 0.8 to 1.5 times the test object's thickness, with a maximum difference in thickness of 20 mm from the test object. The reference block's centerline should have no angle smaller than 40° at the bottom, as shown in Figure 9. Additionally, the minimum thickness of the reference block should be selected to ensure that the beam intersection point of the chosen setup is always within the reference block, as shown in Figure 10. The length and width of the reference block should be sufficient to include all artificial discontinuities within the area of interest in the appropriate scan range. For longitudinal weld testing in cylindrical test objects, curved reference blocks should be utilized with diameters ranging from 0.9 to 1.5 times the test object's diameter. In instances where the test object has a diameter of 300 mm or greater, a flat reference block may be used.
- To ensure accuracy in thickness measurements, a minimum of three reflectors are needed for thicknesses between 6 mm and 25 mm, while a minimum of five reflectors are necessary for thicknesses greater than 25 mm. Side-drilled holes and notches are common reference reflectors used, with various notch shapes acceptable as long as they generate diffracted signals.



Key

t_{max} maximum thickness of reference block
Z depth position of the beam intersection point
S half PCS
α beam angle

Figure 9 - Maximum thickness restriction



Key

t_{min} minimum thickness of the reference block

Z depth position of the beam intersection point

Figure 10 - Minimum thickness restriction

Weld testing

- The probes are scanned parallel to the weld at a fixed distance and orientation in relation to the weld centerline.
- Data collected during a scan can be used for detection and sizing purposes.
- Further evaluation of TOFD indications as detected during the initial scanning may require additional scans such as offset scans, scans perpendicular to the discontinuity or complementary TOFD setups.
- Scanning speed shall be chosen such that satisfactory images are generated. The scanning speed is dependent on scan increment, signal averaging, pulse repetition frequency, data acquisition frequency, and the volume to be tested.
- When scanning circumferential welds, the same overlap is required for the end of the last scan with the start of the first scan.
- Reduction of signal amplitude of lateral wave, back-wall signal, grain noise, or mode-converted signals during a scan by more than 12 dB can indicate loss of coupling (see Figures 11 and 12).

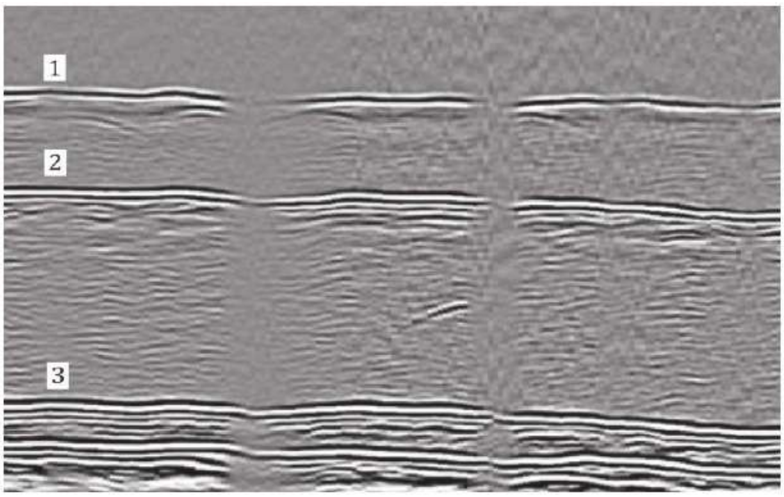


Figure 11 - Loss of signals due to lack of couplant
1 - lateral wave, 2 - back-wall reflection, 3 - mode-converted signal

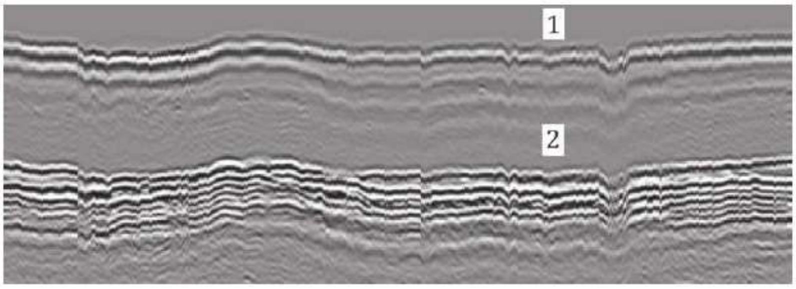


Figure 12 - Image influenced by variation of couplant layer thickness (may be straightened by software
1 - lateral wave, 2 - back-wall reflection

Interpretation and analysis of TOFD data

The Interpretation and analysis of TOFD images are generally performed by:

a) assessing the quality of the TOFD image.

A TOFD test must be conducted in a manner that produces satisfactory images that can be confidently evaluated. The acceptability of images is determined by appropriate criteria, including:

1) coupling;
2) data acquisition;
3) sensitivity setting;
4) time-base setting.

The evaluation of TOFD image quality is a task that requires skilled and experienced operators. It is the responsibility of the operator to determine whether unsatisfactory images necessitate new data acquisition (i.e., re-scanning). Figure 3 provides examples of both satisfactory and unsatisfactory TOFD images.

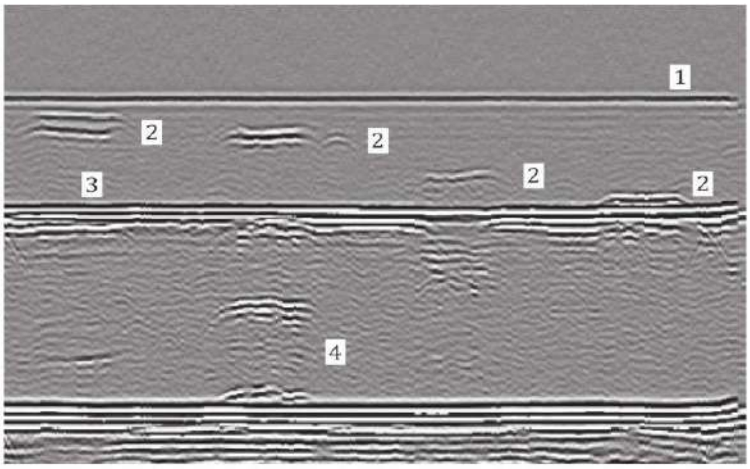


Figure 13 - Satisfactory TOFD image

1 - lateral wave, 2 – indication(s), 3 - back-wall reflection, 4 - mode-converted signal(s)

b) Identification of relevant TOFD indications.

To ensure a satisfactory TOFD image, it is necessary to assess it for the presence of TOFD indications, which can be identified as patterns or disruptions within the image. The TOFD technique can image both discontinuities in the weld and geometric features of the test object, although identifying TOFD indications of geometric features requires a comprehensive understanding of the test object. TOFD indications arising from the intended or actual shape of the test object are classified as non-relevant. Figure 14 provides examples of geometric TOFD indications. To determine whether a TOFD indication is relevant (for example, caused by a discontinuity), its pattern or disruption must be evaluated by considering its shape and signal amplitude relative to the general noise level. Determining the extent of a TOFD indication may require taking into account the grey level values or patterns of neighboring sections.

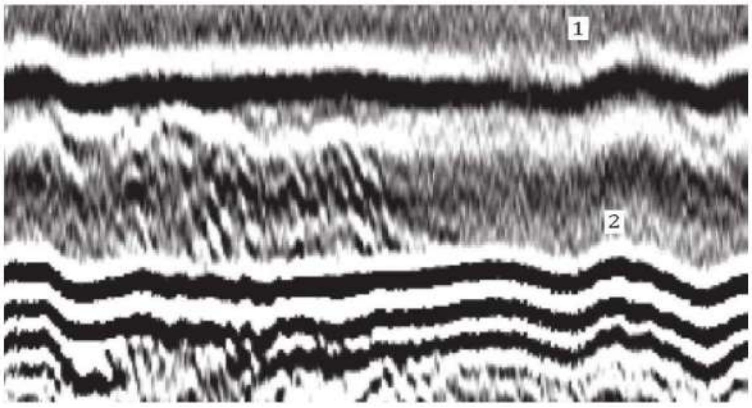


Figure 14 - Gain setting too high
1 - lateral wave, 2 - back-wall reflection,

c) Classification of relevant TOFD indications

The amplitude, phase, location, and pattern of pertinent TOFD indications can convey information about the nature of a discontinuity. By examining these characteristics, relevant TOFD indications can be classified as originating from either surface-breaking or embedded discontinuities.

1) disturbance of the lateral wave;
2) disturbance of the back-wall reflection;
3) TOFD indications between lateral wave and back-wall reflection;
4) phase of TOFD indications between lateral wave and back-wall reflection;
5) mode-converted signals after the first back-wall reflection.

Figure 15 presents several common TOFD images depicting discontinuities in fusion-welded joints.

Figure 15 - Gain setting too low
1 - lateral wave, 2 - back-wall reflection,

d) Determination of location

ISO 16828 defines the determination of the location of a discontinuity in both the x-direction and z-direction, based on the data collected. A point-like discontinuity can be sufficiently described by its x-coordinate and z-coordinate, while elongated discontinuities require the description of their extremities' x-coordinates and z-coordinates. If the location in the y-direction is needed, additional scans will be necessary. To obtain a more precise determination of the location, reconstruction algorithms like synthetic aperture focusing calculations (SAFT) may be employed.

e) Evaluation against acceptance criteria

Once all pertinent TOFD indications have been classified and their location and size have been determined, they must be assessed against specified acceptance criteria. This evaluation will enable the categorization of TOFD indications as either "acceptable" or "not acceptable".

Test report

A TOFD test report shall include at least the following information:

a) a reference to this document (for example ISO 10863);

b) information relating to the object under test, like:
1) identification of the object under test;
2) dimensions including wall thickness;
3) material type and product form;
4) geometrical configuration;
5) location of tested welded joint or joints;
6) reference to welding process and heat treatment;
7) surface condition and temperature, if outside the range 0 °C to 50 °C;
8) stage of manufacture.

c) information relating to the test equipment, namely:

1) manufacturer and type of the TOFD equipment including scanning mechanisms with identification numbers if required;
2) manufacturer, type, frequency, transducer size and beam angle or angles of the probes with identification numbers if required;
3) details of the reference block or blocks with identification numbers if required;
4) type of couplant used;

d) information relating to the test technique, namely:

1) testing level and reference to a written test instruction or procedure, if required;
2) purpose and extent of test;
3) details of datum and co-ordinate systems;
4) details of TOFD setups;
5) method and values used for range and sensitivity settings;
6) details of signal averaging and scan increment setting;
7) details of offset scans, if required;
8) access limitations and deviations from this document, if any;

e) information relating to the test results, like:

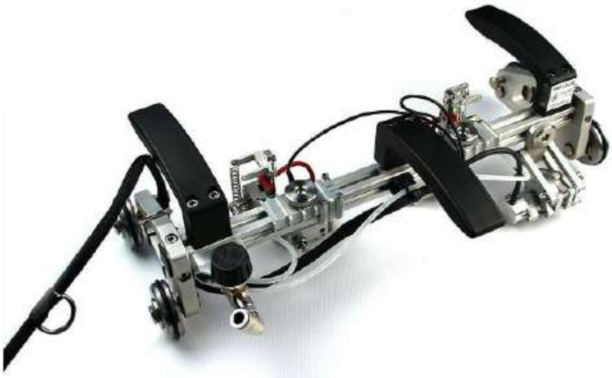
1) acceptance criteria applied;
2) TOFD images of at least those locations where relevant not-acceptable TOFD indications have been detected;
3) tabulated data recording the classification, location and size of relevant TOFD indications and results of the evaluation;
4) date of test;
5) names, signatures and qualification of personnel.

TOFD equipment

Over the last decades TOFD method has become a widely used NDT method, for fast and reliable UT of welded joints. TOFD offers great accuracy for measuring the critical size of crack-like-defects. The accuracy of ±1 mm can be obtained in a wide range of material thickness.

The diffraction technique provides critical sizing capability with relative indifference to bevel angle or flaw orientation.

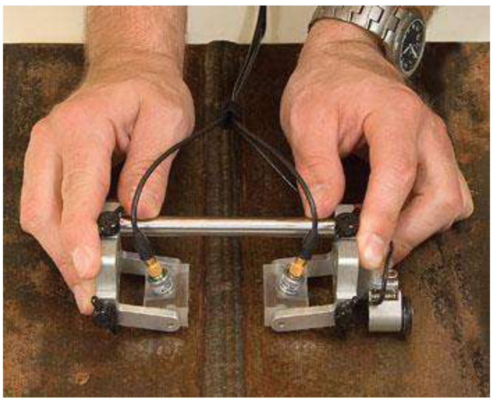
TOFD can also be utilized on its own or in conjunction with other NDT techniques.



TOFD Man ultrasonic weld testing equipment

TOFD Transducers & Wedges

TOFD Caliper - Compact Single Axis Scanner



TOFD manual scanner

TOFD 2.2 PRO Wireless System

Figure 16 - TOFD equipment

2.8.3. Digital radiography

Digital radiography is an advanced technology that utilizes digital detector systems to display x-ray images directly on a computer screen without requiring developing chemicals or intermediate scanning. The incident x-ray radiation is first converted into an equivalent electric charge and then transformed into a digital image by a detector sensor.

Flat panel detectors offer high-quality digital images with superior signal-to-noise ratios and improved dynamic ranges compared to other imaging devices, resulting in heightened sensitivity for radiographic applications. These detectors operate through two approaches: indirect conversion and direct conversion.

Indirect conversion flat panel detectors utilize a photo diode matrix of amorphous silicon, while direct conversion flat panel detectors use a photoconductor, such as amorphous selenium (a-Se) or cadmium telluride (Cd-Te), on a multi-micro electrode plate, resulting in the greatest sharpness and resolution. Both types of detectors' information is read by thin film transistors.

In the direct conversion process, photons hitting the photoconductor, such as amorphous selenium, are directly converted to electronic signals that are then amplified and digitized. This method does not use a scintillator, resulting in no lateral spread of photons, producing a sharper image. This distinguishes it from indirect conversion.

ISO 17636-2 – refers to „Non-destructive testing of welds - Radiographic testing - Part 2: X- and gamma-ray techniques with digital detectors”.

ISO 10675-2 – refers to „Non-destructive testing of welds - Acceptance levels for radiographic testing - Part 2: Aluminium and its alloys”.

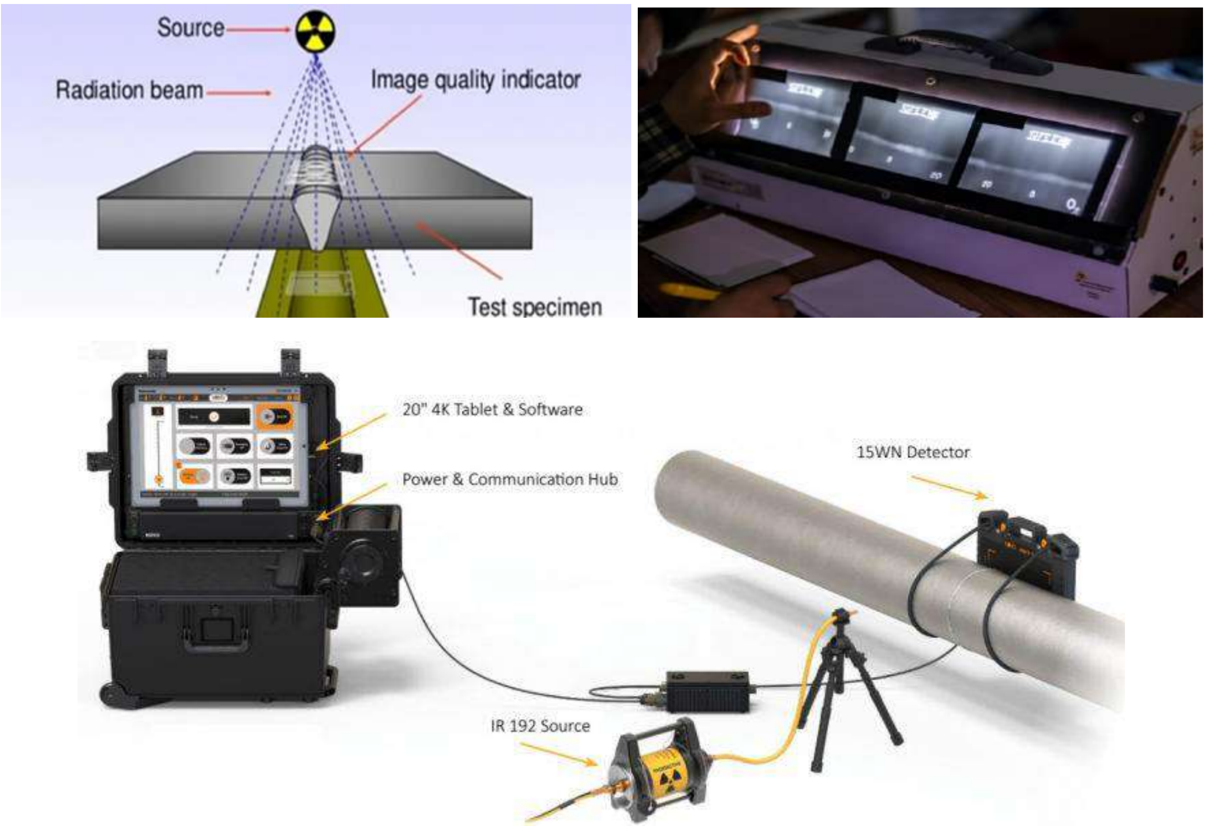


Figure 17

Advantages of Digital radiography

- High-quality images
- High probability of detection
- Lower cost compared with conventional radiography
- No film and film developing costs
- Reusable plates
- Reduced image processing time
- Low environmental impact

Disadvantages of Digital radiography

- Hazardous to operators and other nearby personnel;
- High degree of skill and experience is required for exposure and interpretation;
- The equipment is relatively expensive (especially for x-ray sources);
- The process is generally slow;
- Highly directional (sensitive to flaw orientation);
- Depth of discontinuity is not indicated;
- It requires a two-sided access to the component.

Digital radiography Principles

Radiographic testing contributes to delivering a permanent and strong record as an X-ray image (figure 18) which gives us an understanding & knowledge of the internal structure of the substance. The portion of energy that is consumed by the subject relies on its density and thickness, and the energy that is not consumed by the subject is thus exposed to the radiographic film.

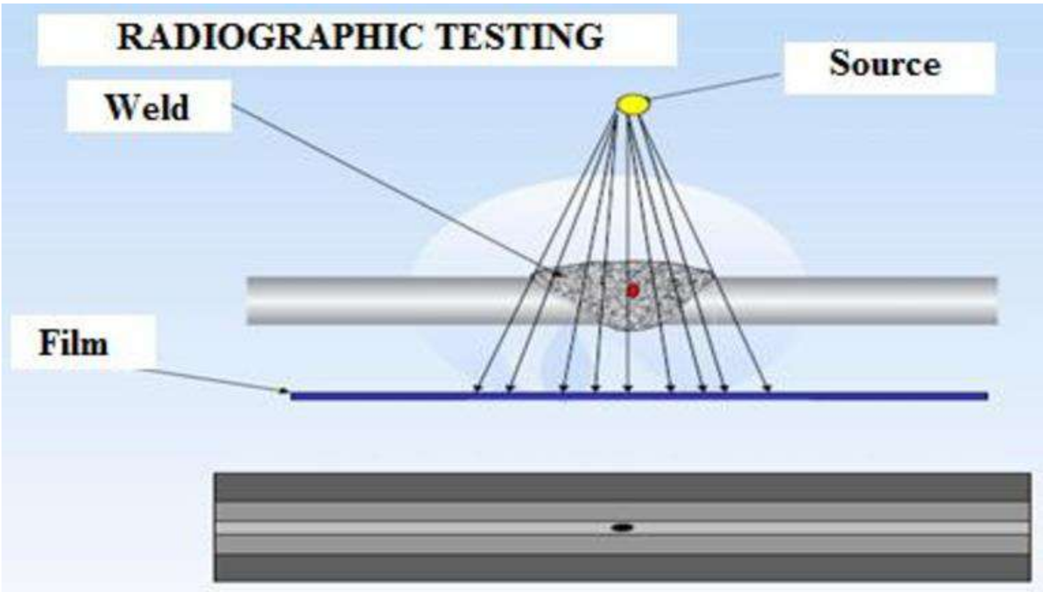


Figure 18

Additionally, there are a lot of benefits of the Radiography Test. You can learn more about its benefits in the next segment.

The Basic Principle: In radiographic testing, the part to be inspected is placed between the radiation source and a piece of radiation sensitive film. The radiation source can either be an X-ray machine or a radioactive source (Ir-192, Co-60, or in rare cases Cs-137). The part will stop some of the radiation where thicker and more dense areas will stop more of the radiation. The radiation that passes through the part will expose the film and forms a shadowgraph of the part. The film darkness (density) will vary with the amount of radiation reaching the film through the test object where darker areas indicate more exposure (higher radiation intensity) and lighter areas indicate less exposure (lower radiation intensity).

This variation in the image darkness can be used to determine thickness or composition of material and would also reveal the presence of any flaws or discontinuities inside the material.

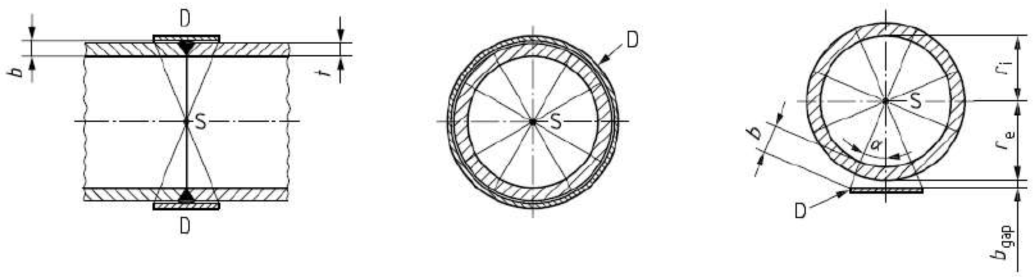
It is established on the principle that radiation is consumed and dispersed when it passes through a subject. If there are differences in density or thickness in the subject then more or less radiation passes through and thus, results in affecting the exposure of the film.

Classification of radiographic techniques

The radiographic techniques are divided into two testing classes:

1. testing class A: basic techniques;
2. testing class B: improved techniques.

Testing class B techniques are utilized when class A techniques do not provide sufficient sensitivity. It is possible to use radiographic techniques with even higher sensitivity than testing class B, but the test parameters must be agreed upon by the contracting parties. The choice of digital radiographic technique must also be agreed upon. The visibility of flaws using film radiography or digital radiography is considered equivalent when using testing class A and testing class B techniques, respectively, and shall be proven by the use of IQIs according to ISO 19232-1 or ISO 19232-2 and ISO 19232-5. In cases where it is not possible to meet the conditions specified for testing class B due to technical or industrial reasons, such as the type of radiation source or the source-to-object distance, it may be agreed upon by the contracting parties that the condition selected can be that specified for testing class A. The loss of sensitivity shall be compensated by increasing the minimum grey value and SNRN for CR or SNRN for the DDA technique (recommended increase of SNRN by a factor > 1.4). If the correct IQI sensitivity is achieved, the test specimen may be regarded as tested to testing class B despite using testing class A conditions. However, this does not apply if the special SDD reduction for test arrangements (Figure 19 to Figure 20) is used.



a) With curved detectors b) With planar detectors

Figure 19 - Arrangement for testing of welds with centrally located radiation source (central projection) and the detector outside

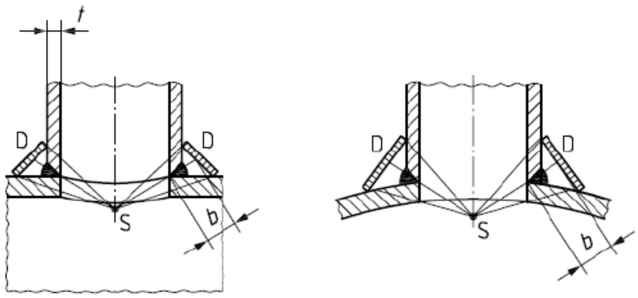


Figure 20 - Arrangement for testing of set-on welds with a radiation source, located on the central pipe axis and perpendicular to the weld centre, and the detector outside

Compensation principles

Compensation principles - three compensation principles are utilized for digital radiography to attain adequate contrast sensitivity. These principles necessitate achieving a minimum contrast-to-noise ratio (CNRN) normalized to the detector's basic spatial resolution per detectable material thickness difference (Δw). If the required CNRN per Δw cannot be accomplished because of an insufficient value of any of the parameters, an increase in SNR can be used as compensation.

Compensation principle I - Compensation for reduced contrast (e.g. by increased tube voltage) by increased SNR (for example by increased tube current or exposure time).

Compensation principle II - Compensation for insufficient detector sharpness (the value of *SRb* is higher than specified) by increased SNR (increase in the single IQI wire or step-hole value for each missing duplex wire pair value). *SRb* is *SRb* detector for detector selection (IQI on the detector without object) or *SRb* image for image quality evaluation of a production radiograph with the IQI on the source side of the object.

Compensation principle III - Compensation for increased local interpolation blunt, due to bad pixel correction for DDAs, by increased SNR.

Theoretical background - These compensation principles are based on the approximation given in Formula for small flaw sizes (Δ*w* way bigger than *w*).

General preparations and requirements

General preparations and requirements

a) Protection against ionizing radiation

The use of X-ray equipment or radioactive sources can pose a significant risk to human health, and as such, appropriate health and safety measures must be implemented whenever such equipment is in use. It should be noted that there may be additional information and regulations related to this matter on a local, national, or international level.

b) Surface preparation and stage of manufacture

Surface preparation is not usually required for digital radiography. However, if surface imperfections or coatings can affect the detection of defects, the surface should be ground smooth or the coatings should be removed. The digital radiography process should be carried out after the final stage of manufacture, such as after grinding or heat treatment, unless otherwise specified.

c) Location of the weld in the radiograph

If the digital radiograph fails to show the weld, it is necessary to place high-density markers on both sides of the weld outside the weld area to evaluate it (WAE).

d) Identification of radiographs

Each section of the object that is undergoing digital radiography must be marked with symbols. These symbols should be visible in the digital radiograph outside of the WAE, if possible. The symbols must enable clear identification of each section. It is also possible for another identification system to be agreed upon as part of the contract.

e) Marking

In order to accurately locate the position of each digital radiograph, permanent markings shall be made on the object to be tested. These markings may include a zero-point, direction, identification, and measure. However, if the material and/or its service conditions do not permit permanent marking, the location may be recorded through accurate sketches, photographs, or automated positioning systems.

f) Overlap of digital images

To ensure complete coverage of the weld area of an object being digitally radiographed with two or more separate detectors, there should be sufficient overlap between the imaging plates. This can be verified by using a high-density marker on the surface of the object that appears on each digital image. If CR or DDA is used, the marker should be visible on each radiograph taken sequentially. This requirement also applies to DDA in manual testing and automated testing in start/stop mode, but not for automated testing in continuous mode. The use and number of high-density markers in the latter case should be agreed upon by both parties involved in the contract.

g) Types and positions of image quality indicators (IQIs)

To ensure the quality of radiographs, image quality indicators (IQIs) as per ISO 19232-5 and ISO 19232-1 or ISO 19232-2 shall be used. In case the material group of the test object or component fits better, IQIs conforming to ASTM E747 or JIS Z2306 may be used. Upon agreement between the parties involved, other IQIs with identical radiographic attenuation as the test object and the same dimensions as specified in ISO 19232-1 or ISO 19232-2 may also be used.

- Duplex wire IQIs - To verify the basic spatial resolution of the digital detector system (SRb detector), a reference image is necessary. The duplex wire IQI (ISO 19232-5) should be placed directly on the digital detector for this purpose. This will allow the determination of the basic spatial resolution or duplex wire value, which is required to ensure that the hardware of the system meets the requirements based on the thickness of the penetrated material. If the geometric magnification technique is applied with a value greater than 1.2 (v bigger than 1.2), then the use of a duplex wire IQI (ISO 19232-5) on the object is required for production radiographs. The maximum value of the basic spatial resolution, which is measured in the digital image, should not exceed the SRb image values specified as a function of the penetrated material thickness (please see Annex C). Automated DDA inspection systems may use either a continuous movement mode (for example translation or rotation) or a start/stop acquisition mode. For single-image inspection, the penetrated material thickness is taken as the single-wall thickness. When positioning the duplex wire IQI, it should be tilted by a few degrees (2° to 5°) to the digital rows or columns of the digital image. In the case of historical images where the IQI was positioned at 45° to the digital rows or columns, the obtained IQI number should be reduced by one.
- Single wire or step-hole IQIs - The IQIs in accordance with ISO 19232-1 or ISO 19232-2 shall be used to verify the contrast sensitivity of digital images. The single wire or step-hole IQIs used shall be placed on the source side of the test object at the centre of the area of interest (AoI) on the

parent metal next to the weld. The identification symbols and lead letter F, when used, shall not be in the WAE unless the geometric configuration makes it impractical. The IQI shall be in close contact with the object's surface and located in a section of uniform thickness characterized by a uniform grey value (mean) in the digital image. The wire IQIs shall be directed perpendicular to the weld, and at least 10 mm of the wire length shall show in a section of uniform grey value or SNRN, which is normally in the base metal adjacent to the weld. When using a step-hole IQI, it shall be placed close to the weld to ensure that the required hole is visible.

h) Evaluation of image quality

The evaluation of digital images shall take place on a monitor. To determine the smallest wire or hole that can be discerned, the radiographic image of the wire or step-hole IQI shall be tested. A continuous length of at least 10 mm of a wire is accepted if it is clearly visible in a section of uniform grey values, typically in the HAZ near the weld. For step-hole-type IQI, both holes of the same diameter shall be discernible to consider the step as visible. The profile function of the image processing system in the linear or linearized grey value image shall be used to evaluate the duplex wire IQI.

The image quality shall be determined in the unprocessed image, which is also known as the raw image. The raw image is acquired after image correction (calibration) by offset and gain images and/or firmware corrections. If the images are evaluated after applying digital filters, the wire or step-hole IQIs shall still meet the requirements of the relevant tables in STAS. The IQI values obtained shall be reported in the radiographic testing report, including the type of indicator used as shown on the IQI.

i) Minimum image quality values

The minimum IQI values for metallic materials are presented in Annex B of STAS 17636-2. For non-metallic materials, the requirements or equivalent requirements can be agreed upon by the contracting parties and documented in the report. These requirements should be determined following ISO 19232-4 guidelines.

j) Personnel qualification

Certification of personnel performing non-destructive testing according to this document shall comply with ISO 9712 or any other certification scheme that is internationally or nationally accepted and appropriate for the relevant industrial sector. The certification shall be for radiographic testing, and the personnel shall have an appropriate level of certification. Additionally, the personnel shall provide proof of undergoing further training in digital industrial radiology.

Recommended techniques. Test arrangements

Radiographic techniques, in accordance with Figures 21 to 31, shall be used, if possible.

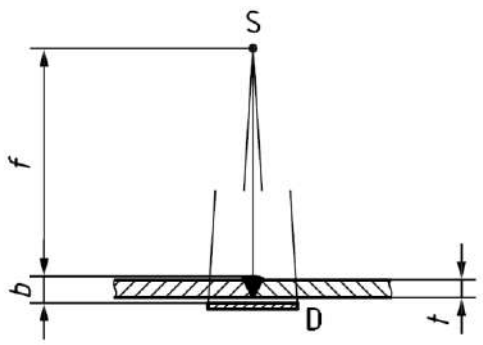


Figure 21 - Arrangement for testing of planar welds with radiation source on one side and the detector on the opposite side

Where:

b - distance of the detector to the source side surface of the object, is less than 1,2

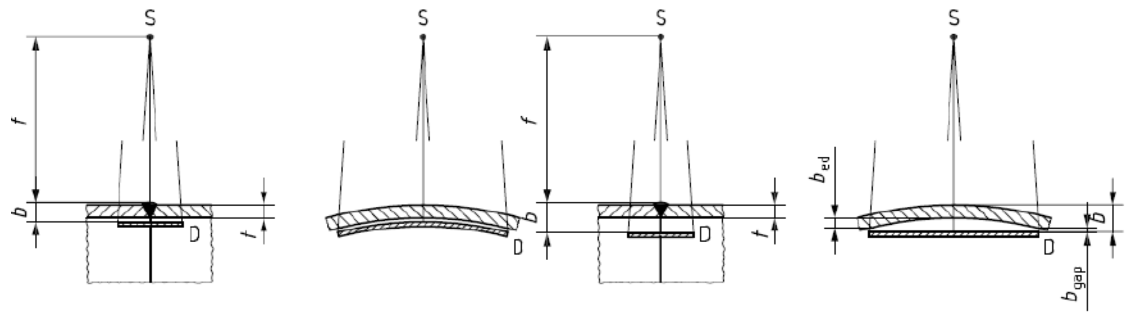
f - the source-to-object distance,

t - wall thickness,

D - diameter,

S - source.

Figure 22 refers to Single-wall penetration of curved objects with the source outside the object



a) With curved detectors *b) With planar detectors*

Figure 22 - Arrangement for testing of curved objects with the radiation source outside and the detector inside

Where:

b - distance of the detector to the source side surface of the object,

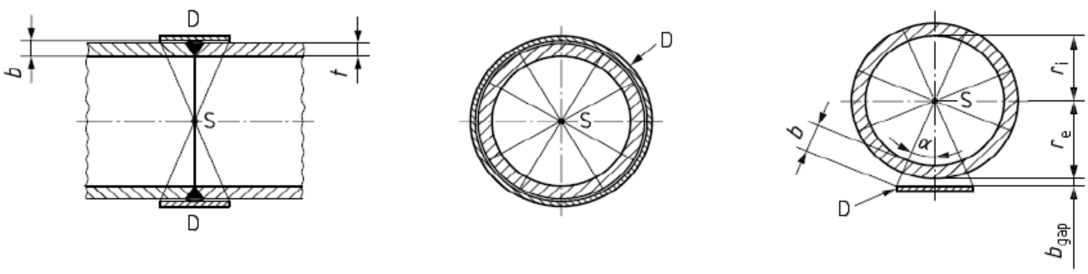
f - the source-to-object distance,

t - wall thickness,

D - diameter,

S - source.

Figure 23 refers to a Single-wall penetration of curved objects with the source inside the object for panoramic exposure.



a) With curved detectors *b) With planar detectors*

Figure 23 - Arrangement for testing of welds with centrally located radiation source (central projection) and the detector outside

Where:

b - distance of the detector to the source side surface of the object,

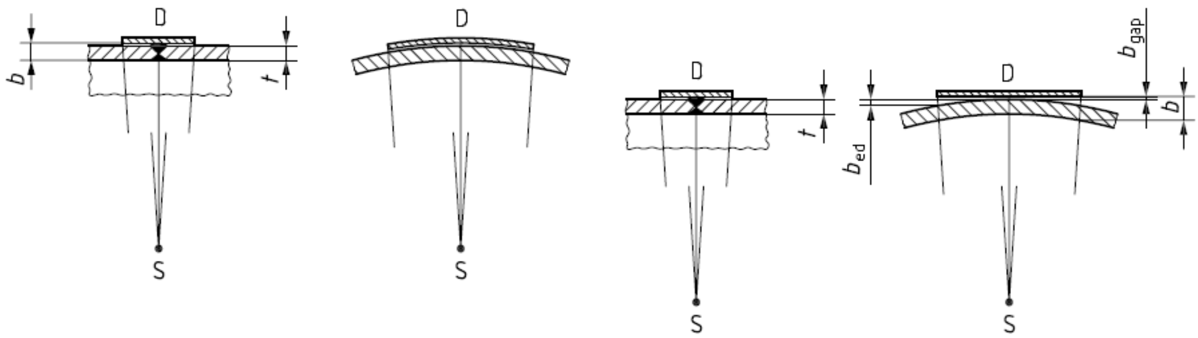
f - the source-to-object distance,

t - wall thickness,

D - diameter,

S - source.

Figure 24 refers to Single-wall penetration of curved objects with the source located off-centre and inside the object.



a) With curved detectors *b) With planar detectors*

Figure 24 - Arrangement for testing of welds with the radiation source located off-center inside the object and the detector outside

Where:

b - distance of the detector to the source side surface of the object,

f - the source-to-object distance,

t - wall thickness,

D - diameter,

S - source.

Figure 25 refers to Double-wall penetration and double-image evaluation (DWDI) of pipes with the elliptic technique and the source and the detector outside the object.

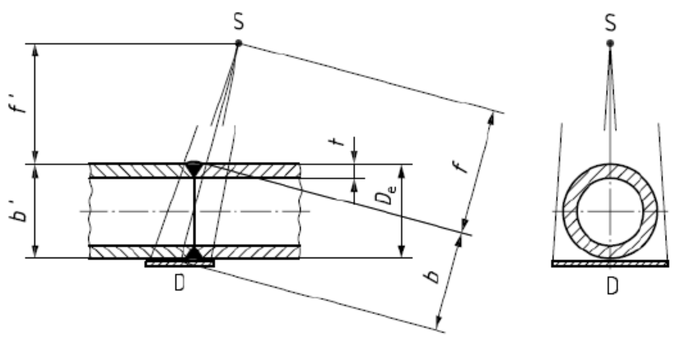


Figure 25 - Arrangement for testing of both walls of pipes with the elliptic technique

Where:

b - distance of the detector to the source side surface of the object,

f - the source-to-object distance,

t - wall thickness,

D - diameter,

S - source.

Figure 26 refers to Double-wall penetration and double-image evaluation (DWDI) with the perpendicular technique and source and detector outside the object.

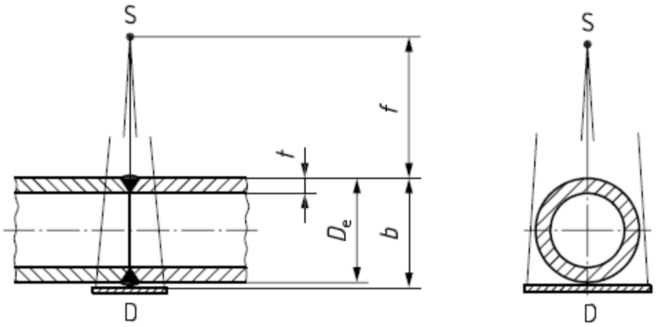


Figure 26 - Arrangement for testing of both walls of pipes with the perpendicular technique

Where:

b - distance of the detector to the source side surface of the object,

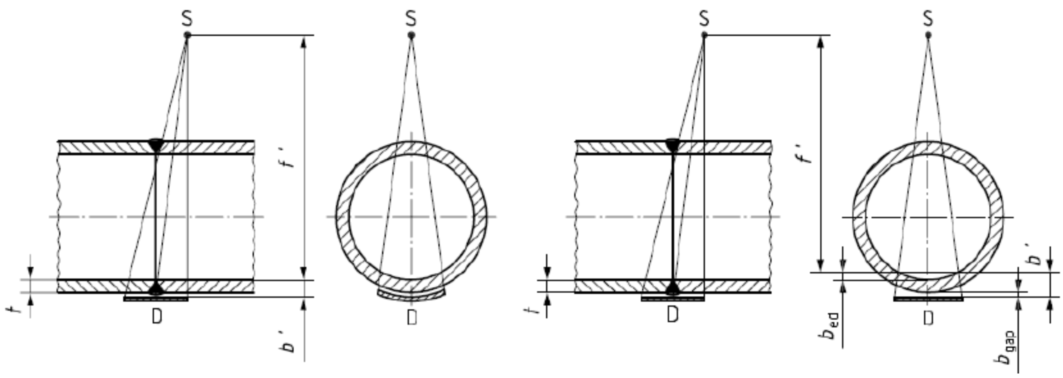
f - the source-to-object distance,

t - wall thickness,

D - diameter,

S - source.

Figure 27 presented Arrangement for testing of curved objects with the radiation source outside and evaluation of the wall next to the detector with the IQI placed close to the detector.



a) With curved detectors *b) With planar detectors*

Figure 27 - Arrangement for testing of curved objects with the radiation source outside and evaluation of the wall next to the detector with the IQI placed close to the detector

Where:

b - distance of the detector to the source side surface of the object,

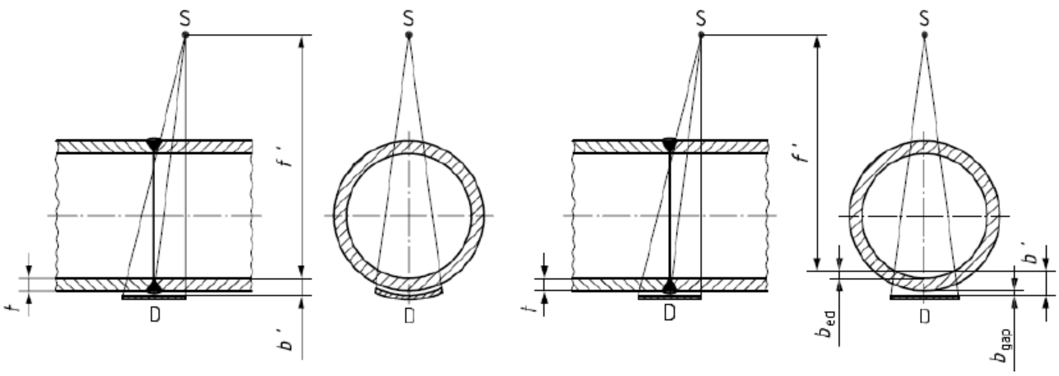
f - the source-to-object distance,

t - wall thickness,

D - diameter,

S - source.

Figure 28 presented Arrangement for testing of curved objects with the radiation source outside, located directly on the surface and evaluation of the wall next to the detector with the IQI placed close to the detector.



a) With curved detectors *b) With planar detectors*

Figure 28 - Arrangement for testing of curved objects with the radiation source outside, located directly on the surface and evaluation of the wall next to the detector with the IQI placed close to the detector

Where:

b - distance of the detector to the source side surface of the object,

f - the source-to-object distance,

t - wall thickness,

D - diameter,

S - source.

Figure 29 presents Penetration of objects with different material thicknesses.

a) Arrangement for testing without compensating edge *b) Arrangement for testing with compensating edge*

Figure 29 - Arrangement for testing of fillet welds with an oblique detector position

Where:

b - distance of the detector to the source side surface of the object,

t - wall thickness,

D - diameter,

S - source,

1 - compensating edge.

Figure 30 presents Arrangement for testing of fillet welds with a perpendicular detector position.

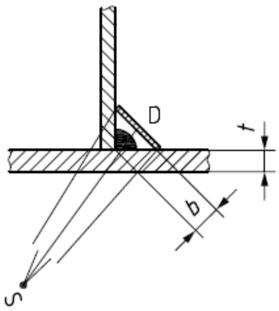


Figure 30 - Arrangement for testing of fillet welds with a perpendicular detector position

Where:

b - distance of the detector to the source side surface of the object,

t - wall thickness,

D - diameter,

S - source.

Figure 31 presents, the Arrangement for testing with a multi-detector technique, applicable for CR.

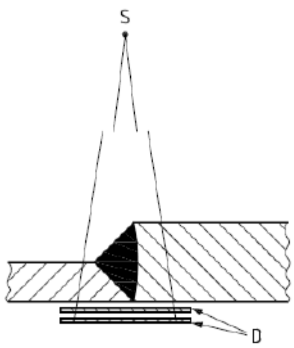


Figure 31 - Arrangement for testing with a multi-detector technique, applicable for CR

Where:

D - diameter,

S - source.

Choice of tube voltage and radiation source

a) X-ray devices up to 1 000 kV: In order to maintain good flaw sensitivity in digital radiography, it is recommended to keep the X-ray tube voltage as low as possible while ensuring a high SNRN (normalized signal-to-noise ratio) in the resulting digital image. The recommended values of X-ray tube voltage for a given penetrated thickness can be found in the diagram provided in ISO 17636-2, which represents best-practice values for film radiography.

However, after accurate detector image correction through calibration, DDAs (digital detector array) can produce sufficient image quality even at higher voltages than those indicated in the ISO 17636-2 diagram.

When using imaging plates with a high structure noise in the sensitive IP (storage phosphor imaging plate) layer (coarse-grained), it is advised to apply approximately 20% less X-ray voltage than what is indicated in the ISO 17636-2 diagram for testing class B. On the other hand, high-definition imaging plates with low structure noise (fine-grained) can be exposed with X-ray voltages equal to or higher than those shown in the ISO 17636-2 diagram, provided that the SNRN is adequately increased.

In certain situations, such as when the object being radiographed has varying thickness throughout its area, a modification of technique using a higher voltage may be necessary. However, it should be noted that using excessively high tube voltage can result in a decreased sensitivity in detecting defects.

b) Other radiation sources: the table 7, provides the recommended penetrated thickness ranges for gamma-ray sources and X-ray equipment above 1 MV. When examining thin specimens, digital radiographs produced by gamma rays from Se 75, Ir 192, and Co 60 sources may not have the same level of defect detection sensitivity as those produced by X-rays with appropriate technique parameters. However, due to the handling and accessibility advantages of gamma-ray sources, Table 2 specifies the thickness ranges for which each of these sources may be used when X-ray tubes are not practical, which should be noted in the report.

In certain situations, wider material thickness ranges may be allowed if sufficient image quality can be achieved.

If digital radiographs are produced using CR (computed radiography) and gamma rays, the total travel time to and from the source position should not exceed 10% of the total exposure time. When using DDAs, the exposure time should begin after the source is in position and end before the source is moved back.

Contracting parties may agree to reduce the penetrated thickness for Ir 192 to 10 mm for testing class A or testing class B if the required image quality is achieved. Similarly, for testing class A or testing class B, the penetrated thickness for Se 75 may be further reduced by agreement between the contracting parties, provided that the specified image quality is attained.

Table 7. Penetrated thickness ranges for gamma-ray sources and X-ray equipment with X-ray potential, U, above 1 MV for steel, copper and nickel-based alloys

Radiation source	Penetrated thickness w mm	
	Testing class A	Testing class B
Tm 170	$w \leq 5$	$w \leq 5$
Yb 169[a]	$1 \leq w \leq 15$	$2 \leq w \leq 12$
Se 75[b]	$10 \leq w \leq 40$	$14 \leq w \leq 40$
Ir 192	$20 \leq w \leq 100$	$20 \leq w \leq 90$
Co 60	$40 \leq w \leq 200$	$60 \leq w \leq 150$
X-ray potentials 1 MV < U ≤ 4 MV	$30 \leq w \leq 200$	$50 \leq w \leq 180$
X-ray potentials 4 MV < U ≤ 12 MV	$w \geq 50$	$w \geq 80$
X-ray potentials U > 12 MV	$w \geq 80$	$w \geq 100$

[a] For aluminium and titanium, the penetrated material thickness is 10 mm ≤ w ≤ 70 mm for testing class A and 25 mm ≤ w ≤ 55 mm for testing class B.

[b] For aluminium and titanium, the penetrated material thickness is 35 mm ≤ w ≤ 120 mm for testing class A.

Monitor viewing conditions and storage of digital radiographs

When evaluating digital radiographs, it is necessary to do so in a darkened room.

The monitor used for image evaluation must also meet the following minimum requirements:

a) have a minimal brightness of 250 Candelas per square meter;

b) display at least 256 shades of grey;

c) have a minimum displayable light intensity ratio of 1:250;

d) display at least 1 million pixels of a pixel size lower than 0.3 mm.

The original images must be stored at full resolution as provided by the detector system. Only image processing related to detector image correction, such as offset (background) correction, gain correction for detector equalization, and bad pixel correction (as described in ASTM E2597), can be applied before storing these raw data to produce artifact-free detector images.

The data storage must be redundant and supported by suitable backup strategies to ensure long-term storage using only lossless data compression.

Test report

To ensure proper documentation of each exposure or set of exposures, a test report must be generated. It includes information on the digital radiographic technique utilized, as well as any unique circumstances that may assist in understanding the results obtained. The test report should contain the following details:

a) A reference to this document, ISO 17636-2:2022;

b) The name of the testing body;

c) The test object;

d) The material being tested;

e) The production stage of the material, such as heat treatment or machining;

f) The type of weld, with an optional photograph if available;

g) The material thickness (t) and the total weld thickness;

h) The welding process;

i) The testing specification, if different or additional to this document;

j) The acceptance requirements, such as ISO 10675-1 or ISO 10675-2;

k) The radiographic technique used in accordance with "Test arrangements" and the required and achieved image quality values (IQI values) as per ISO 17636-2 (Annex B);

l) The magnification used;

m) Description of the marking system used;

n) Position of the detector during the exposure;

o) Type of radiation source, size of focal spot, and identification of the equipment used;

p) Description of the detector, screens, and filters, and the detector's basic spatial resolution;

q) Achieved and required Signal-to-Noise Ratio (SNR) for Digital Detector Arrays (DDAs) or achieved and required grey values and or SNR for Computed Radiography (CR);

r) For CR: scanner type and setup parameters such as pixel size, scan speed, gain, laser intensity, and laser spot size, if available;

s) For DDAs: type and parameters, such as gain, frame time, frame number, pixel size, and image correction procedure (like calibration), if available;

t) Tube voltage used, current, or source type and activity;

u) Time of exposure and distance between the source and the detector;

v) Type and position (detector or source side) of Image Quality Indicators (IQIs);

w) Results of the evaluation, including data on the software used and readings of the IQIs;

x) Parameters used for image processing, such as digital filters;

y) Any deviations from the requirements of this document made by special agreement;

z) Name, certification, and signature of the responsible individual or individuals, such as the RT operator or RT image interpreter;

aa) any unusual features observed during testing;

bb) dates of exposure and test report.

Radiographic technique (ISO 10675-2)

Radiographic technique according to ISO 10675-2 (*Table 8 - Radiographic testing with film (RT-F))* shows the radiographic techniques to be used for RT-F depending on the weld quality level, with either class A or class B techniques in accordance with ISO 17636-1.

Table 8 - Radiographic testing with film (RT-F)

Quality levels in accordance with ISO 10042	Testing techniques and classes in accordance with ISO 17636-1 for RT-F	Acceptance levels in accordance with this document
B	B	1
C	B[a]	2
D	A	3
[a] However, the minimum number of exposures for circumferential weld testing can correspond to the requirements of class A of ISO 17636-1.		

Table 9 - *Radiographic testing with radioscopy (RT-S) and radiographic testing with digital detectors (RT-D)*" shows the radiographic techniques to be used for RT-S or RT-D depending on the weld quality level, with either class A or class B techniques in accordance with ISO 17636-2.

Table 9 - Radiographic testing with radioscopy (RT-S) and radiographic testing with digital detectors (RT-D)

Quality levels in accordance with ISO 10042	Testing techniques and classes in accordance with ISO 17636-2 for RT-S and RT-D	Acceptance levels in accordance with this document
B	B	1
C	B[a]	2
D	A	3
[a] However, the minimum number of exposures for circumferential weld testing can correspond to the requirements of class A of ISO 17636-2.		

Before radiographic testing, welded joints' accessible areas must undergo visual testing in accordance with ISO 17637 and be evaluated. ISO 17635 provides guidance on the NDT for testing and evaluation of fusion welds in metallic materials. The acceptance levels established in this document are applicable for imperfections that cannot be detected and assessed visually. However, surface imperfections that cannot be evaluated by visual testing due to the object's geometry, such as undercut and excessive penetration, surface damage, and weld spatter, may require specific testing for quantification if the interpreter suspects that the ISO 10042 quality levels are not met.

If quantification of undercut and/or excessive penetration through radiographic testing is necessary, specific procedures that use test exposures may be applied to establish a basis for approximate quantification in line with ISO 10042 requirements. The adopted specification/procedure must specify this. When evaluating whether a weld meets the requirements specified for a weld quality level, the dimensions of indications found in a radiograph of the weld must be compared to the sizes of imperfections permitted by enforced standards.

Digital radiography Equipment

Radiographic Testing

Retrofits for portable X-ray machine

Radiographic Testing

Negatoscop

Figure 32

Common application of this testing technique are used in:

- Aerospace product examination;
- Detection of Corrosion Under Insulation (CUI) in petrochemical, oil and gas and power generation industries;
- Detection of Flow accelerated corrosion;
- Foreign object detection;
- Casting and weld inspection;
- Inspection of composites and fiber reinforced components.

2.8.4. Acoustic emission testing

Acoustic emission testing (AE) is a type of non-destructive testing (NDT) that can detect and track the emission of ultrasonic stress waves from specific sources when a material undergoes deformation due to stress.

To perform acoustic emission testing, small sensors are affixed to the component being tested. These sensors convert stress waves into electrical signals, which are sent to a PC for processing. The waves are generated by exposing the component to an external stimulus, such as high pressure, loads, or temperatures. As damage accumulates in the component, more energy is released, leading to an increase in the detected acoustic emission activity and loudness.

Acoustic emission can be likened to small earthquakes that occur within the material. This technique enables the global monitoring of components for defects, enabling large structures and machines to be monitored during operation with minimal disruption, unlike destructive testing. By utilizing multiple sensors, acoustic emission sources and their corresponding damage locations can be identified. Moreover, through signal analysis, different source mechanisms can also be identified.

Advantages:

- Ability to detect a range of damage mechanisms;
- Can be conducted during operation;
- Can locate damage sources and can be differentiate these;
- Global monitoring of a structure;
- Assesses the structure or machine under real operational conditions;
- A non-invasive method;
- Operational in hazardous environments;
- Can be conducted remotely;
- Can detect damages in defects that are difficult to access.

Limitations:

- Limited to assessing structural integrity or machine health by locating issues;
- Cannot detect defects that may be present, but that do not move or grow;
- Can be slower than other non-destructive testing techniques.

Acoustic emissions occur when a material is subjected to stress, such as holding a heavy load or experiencing extreme temperatures. These emissions are typically associated with defects or damage occurring within the structure emitting them, and this is what inspectors aim to detect during an AE test. Acoustic emission sources can stem from a variety of factors, including phase transformation, thermal stress, cool down cracking, melting, and bond or fiber failure.

During an acoustic emission test, an inspector utilizes one or more sensors to capture elastic ultrasonic waves that travel through the surface of a solid material. These waves encounter any defects they come across, leading to changes in their speed and amplitude that inspectors can use to identify the presence of defects. Acoustic emission testing typically employs ultrasound in the range of 20 KHz to 1 MHz.

The terms ultrasonic and ultrasound describe sound waves that are too high-pitched for humans to hear. Acoustic emission, on the other hand, refers to the generation of transient waves during the rapid release of energy from localized sources within a material.

Inspectors typically use AE to look for:

- Corrosion - on the surfaces of various types of materials
- Coating removal - of protective coatings put on materials
- Faults/defects - for monitoring welding and for other general flaw detection
- Leaks - in pipe systems or storage tanks
- Partial discharges - from components subject to high voltage

For fiber specifically, AE is commonly used to test for cracking, corrosion, delamination, and breakages.

Applications

Acoustic emission finds application in a diverse range of materials and contexts. Examples of these applications include:

Structures:

- Bridges and buildings made of concrete;
- Pressure vessels, pipelines, storage tanks, aircraft structures, steel cables, and other metallic structures;
- Composite beams, motorsport structures, and aircraft structures made of composites;

Machines:

- Gearboxes and bearings in rotating machinery, for early wear detection;
- Transformers and bushings in electrical machinery, for partial discharge detection.

Processes:

- Additive manufacturing to assess build quality during the build process;
- Detection of leaks in pressure systems and pipelines;
- Monitoring of particle impacts;
- Frictional processes.

Acoustic emission testing Equipment

A low-noise preamplifier

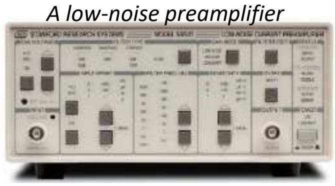


Figure 33

Types of Acoustic Emission Testing Equipment are:

Transducers, Sensors and Strain Gauges. These devices collect raw acoustic emission data. They are also called:

- Piezoelectric transducers
- Piezoelectric sensors
- Strain gauges

The most commonly used transducers for AE testing are two sets of interdigital transducers, which consist of two interlocking, comb-shaped arrays of metallic electrodes arranged like a zipper. One transducer converts electric field energy into mechanical wave energy, while the other transducer converts the mechanical wave energy back into an electric field.

Some examples of different types of acoustic NDT sensors:

- Thickness shear mode resonator: measures metal deposition rates.
- Displacement gauges: convert the acoustic emission of displacement caused by stress on a structure into electronic readings.
- Accelerator gauges: convert the acoustic emission of velocity caused by stress on a structure into electronic readings.

- Bulk acoustic wave device (BAW): propagates waves through the substrate of a material or structure.
- Surface acoustic wave sensor (SH-SAW): a type of BAW device used to detect acoustic emissions on the surface of a material.
- Surface transverse wave sensor (STW): a type of BAW device used to detect acoustic emissions on the surface of a material.

Low-Noise Preamplifiers

- A low-noise preamplifier amplifies the output from the sensors to make it readable for inspectors.
- These devices, combined with the right training, allow inspectors to identify the location of defects in a material that might not be visible to the naked eye.

2.8.5. Leak testing

Leak testing, is an procedure that inspectors use to determine whether an object or system is functioning within a specific leak limit.

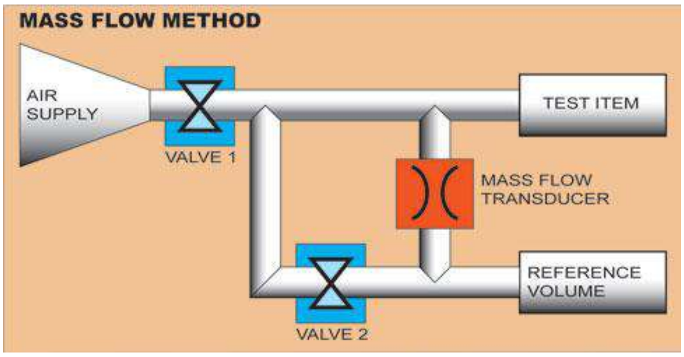


Figure 34

Leaks occur when there is a defect like a hole, a crack, or some other kind of flaw - in an object, allowing whatever the liquid or gas it is holding to flow out. Leak testing uses pressure to find these defects so that they can be addressed as part of regular maintenance procedures.

In general, leak tests are performed on objects that are used to store or move liquids or gases.

Leak testing is a method used by inspectors to detect defects in objects that result in leaks. This is achieved by using pressure to create a flow from higher pressure areas to lower pressure areas, which can be monitored to detect leaks. Leak testing is primarily used to test closed systems for flaws.

The effectiveness of a leak test depends on the type of object being tested. The response of different materials and objects to the high pressures used in leak testing can vary, which can affect the accuracy of the test in detecting the presence and location of defects.

The Key questions at the start of any leak test requirement are:

- What size is the component and what is it's internal volume?
- What is the leak limit?
- Does it have hidden internal volumes that may affect leak measurements?
- Are the parts clean and dry?
- Is there access to inside or is it a sealed unit?

- Is it rigid or flexible?
- Are parts at ambient temperature?
- What is the surface finish of any sealing surfaces?

Key Considerations that need to be taken into account.

As an NDT method, leak testing requires pressure to be inserted into an object to detect leaks, which poses unique considerations for inspectors. Here are some important factors to keep in mind:

- Acceptable Leak Rate: Inspectors and maintenance personnel should be aware of the acceptable leak rate for an object or system before performing a leak test. Different industries have specific guidelines outlining acceptable leak rates for various products and substances. Some leaks may not require immediate action, while others may need further monitoring or repair.

- Manufacturing Considerations: Before performing a leak test, it's crucial to understand the original purpose of the system, part, or object being tested. Manufacturers may have designed the object to either retain or allow liquids or gases to pass through it, depending on its intended use. For example, a car part may be designed to prevent gases from escaping, while an IV may be designed to contain liquids.

- Material Considerations: The material of the object being tested also impacts the leak test and should be considered. If a material is too brittle or too malleable, it may change shape or expand when pressure is introduced, which can affect the accuracy of the test.

- Medium Considerations: The substance that the object is made to hold must be taken into account when planning a leak test. Different substances have varying molecule sizes, and the size of the defect that is acceptable for a particular liquid or gas to escape needs to be known. The pressure range also needs to be considered because different substances respond differently to different pressure ranges, and a pressure range that is too high could damage the object being tested while a range that is too low may return inconclusive results.

Leak Testing Methods:

- **Burst**. This leak test method uses either a destructive or a non-destructive test that ramps pressure in order to find the point at which the device will break open (for example burst).

- **Chamber**. This leak test method is used to identify defects that are causing leaks in a sealed environment, like a device or package, that was not built with an opening to allow for the introduction of pressure for leak testing.

- **Pressure crack**. This leak test method is used to identify "weeping" in valves with a downstream sensor monitor.

- **Pressure or vacuum**. This leak test method uses the pressurization of a test object and a reference volume. If a leak is present, the difference between the two will decrease. (This process is fully automatic.)

- **Pressure decay**. This leak test method uses the pressure change of an object or system under positive pressure to identify defects that are causing leaks.

- **Vacuum decay**. This leak test method uses the pressure change of an object or system under negative pressure to identify defects that are causing leaks.

- **Occlusion**. This leak test method identified obstructions in the flow path of a gas to identify defects that are causing leaks.

- The leak test pressure limit for leak tests typically uses low pressure. Most codes for leak test pressure limits call for the pressure to be at least 15 psi or 25% of the design pressure (whichever pressure is less).

In leak testing materials, inspectors will be looking for defects like:

- Cracks;
- Holes;
- Weak seals;
- And Other flaws or imperfections that may be allowing a gas or liquid to leak out of an object or system.

In the following we will make a short enumeration of The industries that commonly use leak testing, as part of their maintenance processes:

- Automotive;
- Consumer goods;
- Medical Devices;
- Packaging and;
- Sealed Electronics.

Leak testing Equipment

Compact pressure decay leak tester

Air leakage inspection devices

Figure 35

Some examples of the types of equipment that is commonly used for various **Leak Testing** methods, namely:

1. **Air leakage inspection devices -** have displays that show inspectors data from ongoing leak tests. These devices can be used for a variety of types of leak testing, including vacuum decay, pressure decay, burst, chamber, and others.
2. **Compact pressure decay leak tester** - a compact kind leak tester, that can be placed close to fixtures being used in leak testing, allowing inspectors to reduce the amount of connection volume needed for the test. This reduction in volume allows for a decrease in the time needed for the leak test and an increase in test sensitivity.
3. **Large display leak tester -** like the one from Zaxis, (7i) have larger screens, greater internal capacity, larger test volumes, and allow for faster testing.

2.8.6. Floormap inspection

Floormap inspection uses an MFL Array tank floor scanner that offers advanced testing capabilities for tank inspections. This tool has a high probability of detection, including in the critical zone, and can effectively scan thick plates and coatings. Inspectors can differentiate between top and bottom corrosion and get a clear view of the floor beneath coatings to identify corrosion and features such as patch plates and welds. This tool can quickly perform screening, or thoroughly map the entire tank floor while recording all data in an efficient manner. It is capable to detect smaller defects, enabling asset owners to take immediate action and extend inspection intervals.

Tank floor inspection is crucial to ensuring the safety and integrity of storage tanks by preventing leaks and avoiding costly decontamination.

The specialized inspection equipment's address the issue of dead zones and maximizes coverage, reducing dead zones and providing comprehensive and accurate reports to asset owners, allowing them to make informed decisions confidently. The tool generally supports multiple scan modes and customizable reporting options, making it a reliable solution for customers. In general, operators will be able to select pre-planned workflows or create their own, with real-time live displays during data acquisition. These type of tools, combines seamlessly with the laser-assisted defect location feature for rapid and precise flaw detection and identification, resulting in a completely paperless reporting strategy.

Figure 36

The Benefits of floormap inspection:

- **Maximum coverage**, including critical zone
- **High-resolution** for increased Probability of Detection
- **Multi-technology** for top and bottom defect discrimination
- **Flexible scanning**, one scanner with three scan modes
- **Inspect thicker plates** up to 20 mm thickness
- **Unmatched reporting**, comprehensive and on-the-spot
- **10% reporting thresholds**, increase inspection intervals
- **EEMUA 159 and API 653** compliance

Features:

- Precision active steering;
- Interactive laser guide;
- SmartMAGNET;
- Adjustable bridge height;
- Onboard powerful lighting;
- Easy-break

Floormap inspection Equipment

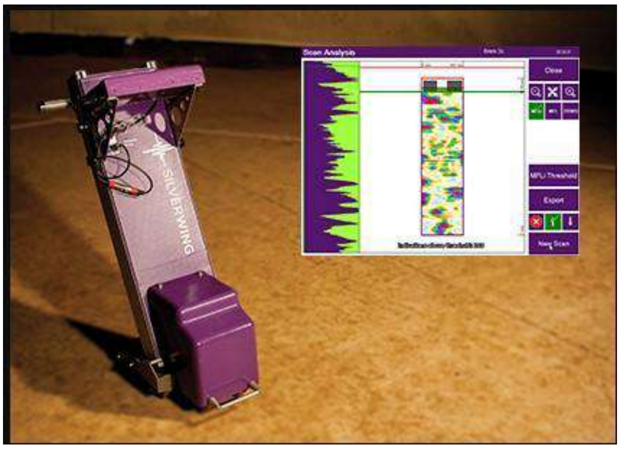


Figure 37

MFL (Magnetic Flux Leakage) inspection service offers a cost-effective and efficient solution for examining tank floors. Our team of certified MFL inspectors possesses extensive expertise in the field. We employ advanced MFL equipment, such as the Floormap VS2i and Floormap 3D, to conduct thorough inspections.

During the inspection process, the tank floor is magnetized using either permanent or electromagnets. Any changes in the magnetic field caused by corrosion, pitting, or wall loss are carefully recorded and analyzed. By assessing the "leakage" of the magnetic field, we can accurately identify the location and severity of defects on both the near and far surfaces of the tank floor.

The equipment can record a comprehensive map that highlights areas affected by corrosion, enabling a clear visualization of the damage. This crucial information can be stored for future reference and planning purposes, aiding in maintenance and repair decisions. With our MFL method, you can expect efficient inspections, accurate defect analysis, and valuable data for long-term management.

2.8.7. Eddy Current Examination

Eddy Current Examination (ECA), appliet to ferrous, non-ferrous and even carbon fibre composite materials in aerospace techniques.

ECA is a non-destructive method applied for examining the surface and its vicinity. It is possible to examine both surfaces and welds of the materials.

Advantages are:

- Quick examination;
- It requires a minimum surface preparation;
- It does not require cleaning the surfaces after the examination, compared to the examination methods: penetrating liquids or magnetic powders;
- Low costs;
- It is a method that can replace the examination with magnetic powders and penetrating liquids.

The **principle of Eddy current examination** is represented by:

Magnetism, the underlying principle behind electric motors and generators, relays, and stereo speakers, is also the force that enables an important category of NDT tools called eddy current testing instruments.

Eddy currents are fields of alternating magnetic current that are created when an alternating electric current is passed through one or more coils in a probe assembly.

Eddy current (EC) **testing** is a no-contact method for the inspection of metallic parts.

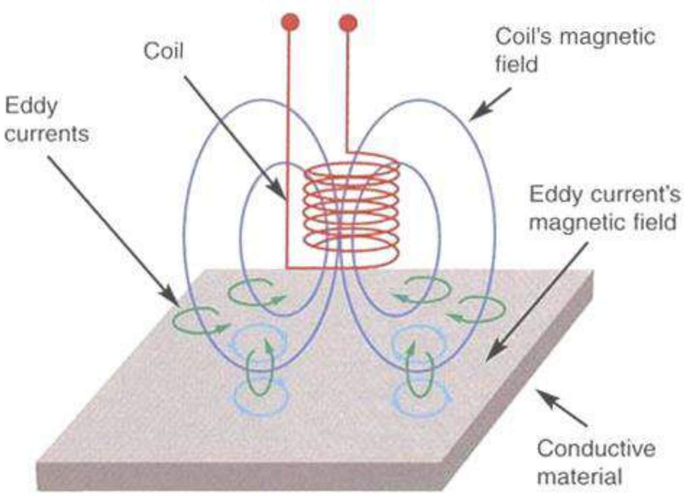


Figure 38

When applying an alternating current to a wire wrapped around a conductor (for example wire in a swirling current), an alternating electromagnetic field is formed around the conductor. Bring this field close to another conductive material (like pipe, pressurised reef, wing area of an aircraft, and so on) and an alternating electric current will flow through that portion of the material as well. This alternating current produces its own secondary magnetic field which interacts the primary field and results in a disturbance of the field around the conductor, as illustrated in the figure shown.

As long as there is no change in the material or its proximity to the conductor, the disturbances will remain constant and can be measured. If while moving along the material under test, the probe passes over a crack, corroded region, pore or other imperfection, a subtle change in the field occurs. This change can be measured and compared with measurements made on similar well known material and the results can be quantified by the operator and the eddy current examination equipment.

Since the magnetic field response depends on the conductivity of the material, the magnetic permeability and the distance of the probe from the conductive surface of the material, examination with eddy currents allows information to be gathered about the location of imperfections or corrosion spots. For example, they can provide information on the physical properties of the material or the thickness of a material's non-conductive coating, such as paint. If the material is not too thick, eddy currents can also measure the thickness of a material.

Changing the excitation frequency of the current probe changes the depth to which the probe can penetrate: the lower the frequency, the deeper it can be measured. Thus, a low-frequency eddy current examination instrument can detect subsurface imperfections or imperfections located on the opposite side of the material being scanned. This makes eddy current testing ideal for detecting corrosion or invisible surface cracks. Often, measurements are made at multiple frequencies to inspect material at multiple depths.

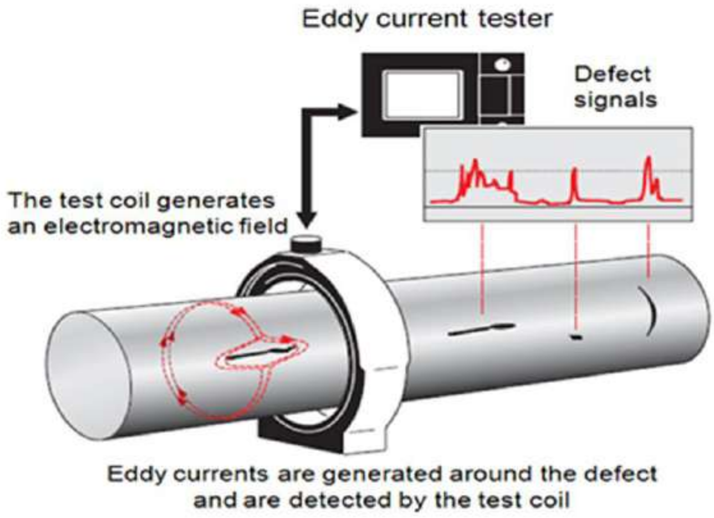


Figure 39

Issues that hinder productivity when this inspection method is used to inspect large areas of complex parts of varying thickness, such as airframes, are:

- a distinction must be made between imperfections and the way the probe moves;
- a sample whose thickness varies a lot requires different measurement methods that require a different parameterization for each thickness (calibration part - for the purpose of adjusting the equipment);
- unlike many other conventional measurement technologies, eddy current examination allows absolute measurements being highly dependent on operators who must have a good knowledge of the type of material to be inspected and the possible imperfections they expect to find.

Therefore, some skills of the operators are needed both to work and to interpret the results.

Pulsatile eddy currents

A new technology, using pulsed eddy currents (transient currents), uses a sinusoidal waveform, rather than a continuous wave, to excite the coil and generate a pulse of eddy currents in the structure of a material.

Benefits:

- is rich in pulsed eddy current having low frequency components to detect imperfections on the surface and inside the material;
- the equipment uses a multitude of individual probes to enlarge the examination area in a single pass;
- eddy currents can be modelled to fit specific geometries (hexagonal, square, plane, complex shapes, etc.).

The key component in any eddy current examination system is the sensor used to measure the magnetic field. Traditionally, these sensors have been inductive coils, although in use for decades, coils have some drawbacks. The physical shape of the coils limits their resolution and the possibilities of measuring deep into the material to be examined, requiring a coil that is insensitive to low-frequency signals.

- To solve this problem, a new product has been developed: reels built on a thin, flexible plastic substrate.

- Instead of wire wrapped around a core, these flexible sensors use metal lines deposited on a flexible plastic material, similar to a flexible printed circuit board. They can be designed with embedded single or multiple coils. The figure shows such an equipment for the eddy current examination of longitudinally welded pipes.

Figure 40

Principal uses:

- Crack detection
- Material thickness measurements
- Layer thickness measurements
- Conductivity measurement for:
  - material identification
  - heat damage detection
  - depth determinations
  - thermal treatment monitoring.

Advantages of eddy current inspection:

- Sensitive to small cracks and other types of imperfections
- Detects surface or near-surface imperfections
- Examination provides immediate results
- Equipment is portable
- Method can be used for more than shape detections
- Minimal parts preparation is required
- Examination probe is not required to touch the part
- Inspects complex shapes and sizes of conductive materials.

The **limitations** of eddy current examinations:

- Only conductive materials can be inspected
- The surface of the part must be accessible to the probe
- Higher skills and training are required than with other techniques
- Surface finish and roughness may interfere
- Reference standards required for installation
- Depth of penetration is limited
- Imperfections.

Basic steps in performing an examination with a surface probe:

- Equipment and probe selection and calibration
- Frequency selection to produce the desired penetration depth
- Adjusting the instrument to obtain an easily recognizable defect response using a standard or configured calibration specimen
- Place control probe (coil) on part surface and set up equipment
- Scanning with the probe on one side of the surface in a pattern that provides complete coverage of the area to be examined. In order to maintain the same orientation to the surface the probe will need to not be tilted, which can affect signal interpretation and affect the examination results. In some cases, it may be necessary to use devices to help maintain orientation or to use automated scanning methods
- Monitor the signal to detect the change in impedance that will occur when the probe moves over a local discontinuity.

The reception of signals from the many transducers located in critical areas is centralised in specialised multi-channel devices (up to 128). The data is transmitted to computerised systems, for rapid analysis and location of sources (hazardous areas).

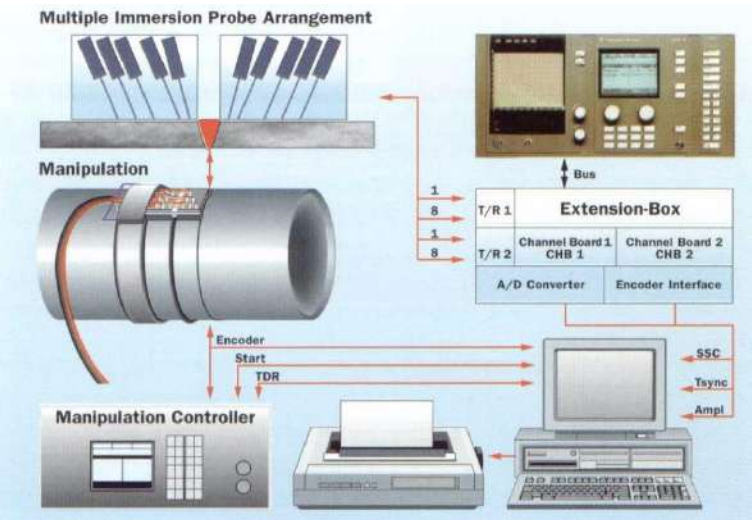


Figure 41 - Example of acoustic emission control

Transducers is an device that allows the transformation of a physical quantity, it is a transformer of acoustic energy into electrical energy.

A transducer is a device that transforms signals of one kind into signals of another kind. According to systems theory, a transducer is a hybrid multiport, meaning that the ports are not of the same nature (e.g. electrical, mechanical, acoustic).

Transducers **classification:**

- Linear – this transducer produces a beam of US parallel to each other and perpendicular to their surface, and a rectangular image will appear on the screen;
- Sectoral - this transducer emits a divergent US beam from a point in the middle of the transducer surface, and a triangular image appears on the screen with the tip on the transducer emission surface. Types of sector transducers: mechanical or electronic;
- single-element - this transducer contains a single piezoelectric part and cannot be electronically activated;

- combined - are complex transducers and incorporate all the possibilities of the single transducers. They have multiple frequencies between 3.5 and 10 MHz.

Each type of transducer has its advantages and disadvantages. Transducers can be used for external applications, or for intraoperative use.

The transducer can act as a transmitter as well as a receiver of ultrasound. It ensures the mutual and successive conversion of electrical energy into mechanical energy. Its active element is the piezoelectric crystal. It has the shape of a disc and is covered on both sides with two metal layers, good conductors of electricity, to which two electrodes are applied, one on each surface.

Applying an electrical voltage between the electrodes will cause the crystal to deform and consequently emit mechanical energy to both surfaces. The metal layers have both the role of transferring the electrical voltage to the crystal and of taking up the electrical impulse created at the surface of the crystal by the action of ultrasound reflected in the tissue. This electrical pulse is then conducted to the amplification system of the device. The thickness of the piezoelectric disc determines the nominal frequency. Its role is to focus and cause each electrical pulse to reinforce the other, thus increasing the transducer's efficiency. In front of the lens is placed an insulating layer with impedance similar to that of the body. Behind the piezoelectric disc is a layer of material that absorbs the US then emitted and dampens vibrations that are not at the desired frequency.

Scanning

In order to perform eddy current testing, the chosen probe(s) should scan both the weld surface and the heat-affected zones. Ideally, the probe should move perpendicular to the main direction of expected discontinuities, but if the direction is unknown or if discontinuities are expected in multiple directions, at least two scans should be conducted, with one perpendicular to the other.

It's important to note that the reliability of eddy current testing is heavily influenced by the coils' orientation relative to the surface being tested. Thus, it's essential to ensure that the probe is at the optimal angle to account for the varying surface conditions in the heat-affected zone.

For differential probes, the sensitivity can be affected by the orientation of the discontinuity relative to the coils. Therefore, it's crucial to control this during testing to obtain accurate results. Eddy current testing can be divided into two parts: the heat-affected zones and the weld surface (Figures 42-44).

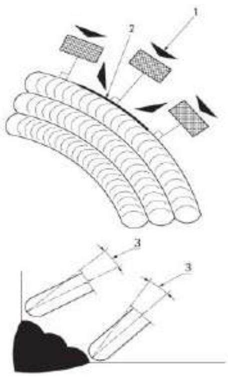


Figure 42 - Base material and heat-affected zone testing

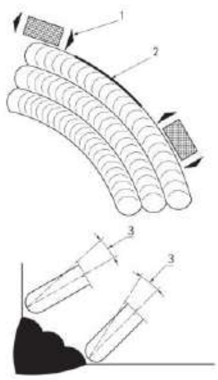


Figure 43 - Base material and heat-affected zone testing

Where: 1 - probe direction; 2 - discontinuity; 3 - optimum angle to accommodate the varying surface conditions

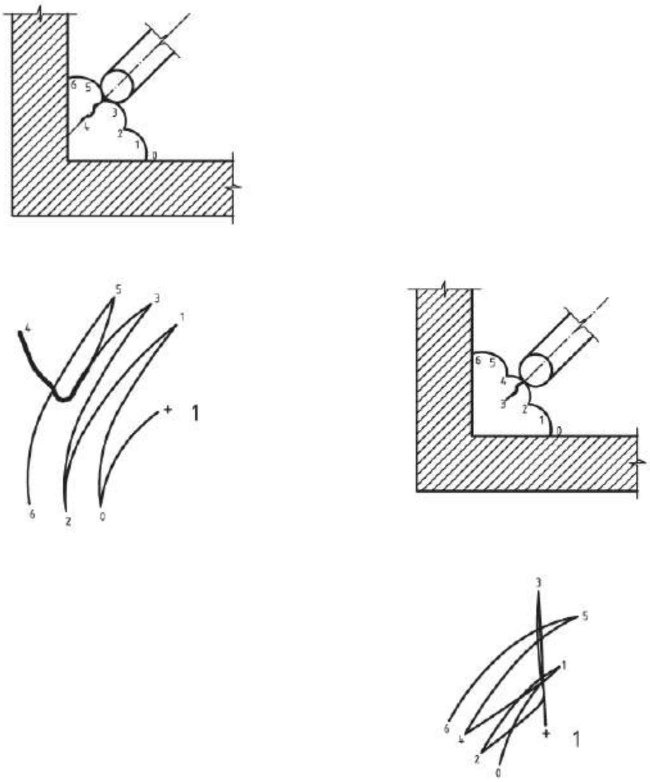


Figure 44 - Typical discontinuity signals generated during weld cap scanning

Where: 0 - balance point; 2 - different positions of the probe

Test report

Prior to conducting eddy current testing, it is necessary to define the test report content using the guidelines specified in ISO 15549.

The minimum information that must be included in the test report comprises:

- The name of the testing company (if applicable)
- Component identification
- Material type
- Coating type and nominal thickness (if applicable)
- Heat treatment details
- Joint type
- Material thickness
- Welding process
- Procedure number
- Acceptance criteria
- Surface preparation
- Extent of testing, including references to relevant drawings
- Description of calibration block
- Test equipment utilized
- Test conditions, such as frequency, sensitivity, and phase
- Calibration report
- Description and location of any unacceptable indications that exceed the acceptance criteria (including sketches or photographs)
- Results of testing

- Inspector's name and test date
- Customer's signature and the signature of the relevant certifying authority (if applicable).

Eddy Current Examination Applications

Figure 45

Common applications that use transducers, include their implementation, in both, ultrasonic welding and ultrasonic examination, both, in the medical field (endoscopes) and in the field of classical or phase array ultrasonic inspection, for example, for tensometry where they allow the measurement of displacements that cannot otherwise be measured using classical measuring means.

2.9. Critical review of selection of NDT methods

2.9.1. Destructive vs. non-destructive testing

The materials testing methods used in the field of welding can be basically divided into two groups, destructive and non-destructive testing (NDT) methods. Between these two groups are the quasi-nondestructive test methods.

The quasi-non-destructive test methods have been developed for the operational characteristics of different significant structures and structural elements. These methods are typically in the experimental or introduction phases. Given the small size of the test specimens, special attention must be paid to the size effect.

For operating structures, complete shutdowns and non-destructive or destructive tests were common. Nowadays, online non-destructive testing is becoming increasingly important.

The benefits of non-destructive testing (NDT) are as follows:

- The part is not changed or altered and can be used after the examination(s);
- Every item or large portions of the material can be examined with no adverse consequences;
- Materials can be examined for conditions internal and at the surface;
- Structures or structural elements can be examined while in service;
- Many NDT methods are portable and can be taken to the object to be examined;
- Overall, NDT testing is cost effective.

The limitations of non-destructive testing (NDT) are as follows:

- It is usually quite operator dependent;
- Some methods do not provide permanent record of the examination;
- NDT methods do not generally provide („exact") quantitative data;
- Orientation of discontinuitities must be considered;
- Evaluation of some test results are subjective and subject to dispute;
- While most methods are cost effective, some can be expensive;
- Defined procedures that have been qualified are essential.

2.9.2. NDT methods during the fabrication processes of pipes

The fabrication of different products is achieved through a series of successive and closely interlinked technological steps. Non-destructive tests may be required during and between each step to verify the adequacy and quality of the process. These non-destructive tests, especially for a structurally or technologically complex product, may be of several types; in the case of welded structures, they are almost always of several types.

2.9.3. Test methods for welded joints and their characteristics

The most commonly used non-destructive testing methods and their abbreviations for testing of welded joints are summarised in the Table 1.

Table 1. Most commonly used non-destructive testing methods for testing of welded joints.

Testing method	Abbreviation
Visual testing	VT
Penetrant testing	PT
Magnetic particle testing	MT
Eddy current testing	ET

Radiographic testing	RT
Ultrasonic testing	UT

2.9.3.1. Visual testing (VT)

Principle: Uses reflected or transmitted light from test object that is imaged with the human eye or other light-sensing device.

Application: Many applications in many industries ranging from raw material to finished products and in-service inspections.

Advantages: Can be inexpensive and simple with minimal training required. There are broad scope of uses and benefits.

Limitations: Only surface conditions can be evaluated. Effective source of illumination is required. Physical access is necessary.

2.9.3.2. Penetrant testing (PT)

Principle: A liquid containing visible or fluorescent dye is applied to surface and enters discontinuities by capillary action.

Application: Virtually any solid nonabsorbent material having uncoated surfaces that are not contaminated.

Advantages: Relatively easy and materials are inexpensive. Extremely sensitive and very versatile method. Minimal training is necessary.

Limitations: Discontinuities open to the surface can be detected only. Surface condition must be relatively smooth and free of contaminants.

2.9.3.3. Magnetic particle testing (PT)

Principle: Test part is magnetized and fine ferromagnetic particles applied to surface, aligning at discontinuities.

Application: All ferromagnetic materials, for surface and slightly subsurface discontinuities. Large and small parts can be tested, too.

Advantages: Relatively easy to use. Equipment and materials are usually inexpensive. Highly sensitive and fast compared to penetrant testing (PT).

Limitations: Only surface and a few subsurface discontinuities can be detected. Only ferromagnetic materials can be investigated.

2.9.3.4. Eddy current testing (ET)

Principle: Localized electrical fields are induced into a conductive test specimen by electromagnetic induction.

Application: Virtually all conductive materials can be examined for flaws, metallurgical conditions, thinning, and conductivity.

Advantages: Quick, versatile, sensitive; can be noncontacting; easily adaptable to automation and in situ examinations.

Limitations: Variables must be understood and controlled. The limitations are ensured from shallow depth of penetration, lift-off effects and surface condition.

2.9.3.5. Radiographic testing (RT)

Principle: Radiographic film is exposed when radiation passes through the tested object (material). Discontinuities affect exposure.

Application: Most materials, shapes, and structures. Examples include welds, castings, composites, etc., as manufactured or in-service.

Advantages: Provides a permanent record and high sensitivity. Most widely used and accepted volume examinations.

Limitations: Limited thickness based on material density. Orientation of planar discontinuities is critical. The radiation hazard requires increased attention.

2.9.3.6. Ultrasonic testing (UT)

Principle: High-frequency sound pulses from a transducer propagate through the tested object (material), reflecting at interfaces.

Application: Most materials can be examined if sound transmission and surface finish are good and shape is not complex.

Advantages: Provides precise, high-sensitivity results quickly. Thickness information, depth, and type of flaw can be obtained from one side of the component.

Limitations: No permanent record (usually). Material attenuation, surface finish, and contour can be presented difficulties. Requires couplant.

2.9.4. Selection of NDT method or methods for welded joints

Items should be considered for the selection of NDT method or methods are as follows:

- Welding processes;
- Base material, welding consumables and any heat treatment;
- Joint type and geometry;
- Component configuration (accessibility, surface condition);
- Quality levels;
- Expected imperfection type and orientation.

Table 2 summarizes recommended methods for detection of accessible surface imperfections for all types of welds including fillet welds. Parentheses indicate that the method (ET) is applicable but the results may provide limited information, unless specific techniques are used.

Table 3.a. summarizes recommended methods for detection of internal imperfections for butt- and T- joints with full penetration made by steels.

Table 3.b. is a continuation of the Table 3.a. and summarizes recommended methods for detection of internal imperfections for butt- and T- joints with full penetration made by aluminium, nickel, copper, titanium and their alloys.

Table 2. Recommended detection methods: surface imperfections.

Imperfections	Materials	Joint type	Testing methods
Accessible surface imperfections	Ferritic steels	All types of welds, including fillet welds (with full penetration)	VT VT and MT VT and PT VT and (ET)
	Austenitic steels, aluminium, nickel, copper, titanium and their alloys		VT VT and PT VT and (ET)

Table 3.a. Recommended detection methods for steels: internal imperfections.

Imperfections	Materials	Joint type	Test methods		
			t ≤ 8	8 < t ≤ 40	t > 40
Internal imperfections	Ferritic steels	Butt-joints	RT or (UT)	RT or UT	UT or (RT)
		T-joints	(UT) or (RT)	UT or (RT)	UT or (RT)
	Austenitis steels	Butt-joints	RT	RT or (UT)	RT or (UT)
		T-joints	(UT) or (RT)	(UT) or (RT)	(UT) or (RT)

Table 3.b. Recommended detection methods for non-ferrous materials: internal imperfections.

Imperfections	Materials	Joint type	Test methods		
			t ≤ 8	8 < t ≤ 40	t > 40
Internal imperfections	Aluminium	Butt-joints	RT	RT or UT	RT or UT
		T-joints	(UT) or (RT)	UT or (RT)	UT or (RT)
	Nickel- and copper-alloys	Butt-joints	RT	RT or (UT)	RT or (UT)
		T-joints	(UT) or (RT)	(UT) or (RT)	(UT) or (RT)
	Titanium	Butt-joints	RT	RT or (UT)	N/A
		T-joints	(UT) or (RT)	UT or (RT)	N/A

Both in Table 3.a. and Table 3.b. parentheses indicate that the method (UT or RT) is applicable but the results may provide limited information, unless specific techniques are used. Furthermore, „t" means in „mm" the nominal thickness of the base material to be welded.

For partial penetration welds and fillet welds, the unfused root can prevent satisfactory volumetric examination when using the methods given in previous and this table. Unless additional test methods are specified to overcome this, the quality of the weld shall be assured by control of the welding process. It may be necessary to carry out tests specific to the joint geometry in order to determine the degree of penetration or to target specific types of imperfection.

Table 4. gives the correlation between the quality levels of ISO 5817 or ISO 10042 and testing techniques, testing levels and acceptance levels for visual testing (VT) standards, as example. The acceptance levels for visual testing (VT) are equal to the quality levels in ISO 5817 or ISO 10042 standards. It is important to note that the correlations are not quantitative links.

Table 4. Correlation table: visual testing (VT).

Quality levels in accordance with ISO 5817 or ISO 10042	Testing techniques and testing levels in accordance with ISO 17637	Acceptance levels
B	Level is not specified	B
C		C
D		D

Similar tables are used for other non-destructive testing methods, of course using the relevant standards.

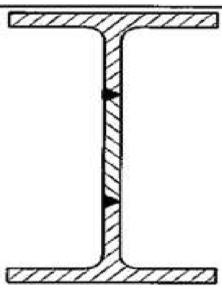
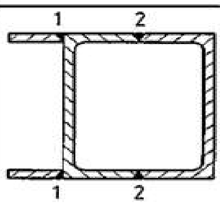
Table 5.a. shows examples for general non-destructive evaluation of welded joints.

Table 5.a. Design and non-destructive testing of welds: examples for general non-destructive evaluation of welded joints.

Serial no.	Example		NDT method					Remarks
			VT	UT	RT	MT	PT	
1a			+	-	(+)	+	+	
1b			+	(+)	+	+	+	
1c			+	+	+	+	+	
1d			+	+	+	+	+	

Table 5.b. shows specific examples for the evaluation of different weld types representing various applications.

Table 5.b. Design and non-destructive testing of welds: examples for the evaluation of different weld types representing various applications.

Serial no.	Example	Welded joint	NDT method					Remarks
			VT	UT	RT	MT	PT	
5b			+	+	+	+	+	
6a		1 2a 2b	+ + (+)	+ + +	(+) + + *)	+ + (+)	+ + (+)	Variant 2a: accessible from all surfaces Variant 2b: not accessible from internal surfaces *) for double wall radiography take thickness into consideration

The symbols used in Table 5.a. and Table 5.b. means as follows:

- \+ the method is applicable and the results will satisfy ordinary requirements;
- (+) the method has a limited application and the method should be supplemented with another method;
- – the method cannot be used or the results are not sufficient.

The examples can be found in table 5.a and Table 5.b. are intended to give guidance when planning for NDT during design and fabrication.

The welding discontinuities guide (see Figure 1.a. and Figure 1.b.) provides a link between the defect and the applicable non-destructive test method or test method variant. There are unsatisfactory (U), possible (P) and applicable (A) variants, marked in red, yellow and green colours, respectively. In the case where a method variant is unsatisfactory (U), the method is marked in orange colour. The numbers indicate the order of preference among the applicable cases.

Type of discontinuity	VT	PT	MT	ET	RT	UT
Crater crack	P	A2/A3	A1/P/P	P	U	P/P
Dense inclusion	U	U/U	U/P/U	U	A1	P/U
Excessive concavity	A1	U/U	U/U/U	U	U	U/U
Excessive convexity	A1	U/U	U/U/U	U	U	U/U
Incomplete penetration	P	U/U	U/U/U	U	A1	U/A2
Lack of fusion	U	U/U	P/P/U	U	A2	P/A1

Symbol	Meaning
U	Unsatisfactory
P	Possible
A1	First order of preference
A2	Second order of preference
A3	Third order of preference

PT: Fluorescant penetrant / Visible penetrant
MT: Wet DC / Dry DC / Dry AC magnetic particle
UT: Straight / Angle beam ultrasonics

Figure 1.a. Guide of welding discontinuities.

Type of discontinuity	VT	PT	MT	ET	RT	UT
Porosity	P	P/P	P/U/U	U	A1	P/U
Slag inclusion	U	U/U	P/A2/U	U	A1	P/P
Subsurface crack	U	U/U	U/U/U	P	A1	A1/A1
Surface crack	P	P/P	U/P/P	P	A2	U/A1
Underbead crack	U	U/U	U/U/U	P	A1	A1/A1
Undercut	A1	U/U	U/U/U	U	U	U/P

Symbol	Meaning
U	Unsatisfactory
P	Possible
A1	First order of preference
A2	Second order of preference
A3	Third order of preference

PT: Fluorescant penetrant / Visible penetrant
MT: Wet DC / Dry DC / Dry AC magnetic particle
UT: Straight / Angle beam ultrasonics

Figure 1.b. Guide of welding discontinuities.

2.9.5. Comparison of the NDT methods: general and cost oriented aspects

Table 6. summarises the main features of the most commonly used non-destructive testing methods for welded joints, as a general comparison.

Table 6. Comparison of the NDT methods: general aspects.

Characteristics	VT	PT	MT	ET	RT	UT
Detectable discon-tinuities	surface	surface	surface and subsurface	surface	„all"	„all"

Relative sensitivity	low	low	low	high	medium	high
Dependence on material quality	weak	weak	strong	strong	moderate	strong
Effect of geometry	low	low	low	high	high	high
Accessibility	essential	essential	lessential	essential	essential	essential
Possible of auto-mation	medium	weak	weak	good	wrong	good
Portability	high	high	high (medium)	high (medium)	low	high

Table 7. summarises the main costs and cost-related characteristics of the most commonly used non-destructive testing methods for welded joints, as a cost oriented comparison.

2.9.6. Short summary and main conclusions

The selection of non-destructive testing (NDT) method(s) for welded joints is a complex task.

The aspects to be considered are partially consistent and partially contradictory.

When selecting the method(s) to be used, the requirements of a number of standards and technical documents have to be taken into account.

The selection of method(s) can be effectively supported by practical experience.

Table 7. Comparison of the NDT methods: cost oriented and cost-related aspects.

Characteristics	VT	PT	MT	ET	RT	UT
Basic cost	low	low	medium	medium	high	high
Cost of use	low	medium	medium	low	high	low
Operator qualification	low	low	low	medium	high	high
Training of the operator	necessary	necessary	significant	significant	significant	significant
Cost of training	unimportant	minimal	low	medium	high	high
Availability of the result	immediately	after a short wait	after a short wait	immediately	later	immediately
Cost of official report	low	low	medium	medium	low	low

2.10. Other test methods: Pressure testing and dimensional tests

2.10.1. Pressure testing of pipelines – principles

Pressure testing of pipelines is necessary for promoting safety and minimizing damage to industrial and commercial facilities. Licensed professionals and appropriate procedures are two key components that ensure the success of this process.

Pressure testing includes a process of ensuring the integrity of a pipeline. In this process, certified professionals subject the pipeline to extreme pressure to ascertain that its pipes, fittings, joints, and other essential components are in such condition that significantly eliminates the risk of gas leakages and piping system explosions.

The extreme amount of pressure the professional subject the pipeline to ensures that it can withstand whatever pressure and function manufacturers build it for throughout its lifetime. Successful gas line pressure testing significantly depends on the expertise and experience of relevant professionals: they must be familiar with the process and the various components.

2.10.2. Pressure testing of pipelines – standards

There are several regulations available for pressure testing:

- BS 31.3 Process piping guide
- EN 1594 Gas infrastructure - Pipelines for maximum operating pressure over 16 bar - Functional requirements
- EN 12327: Gas Infrastructure - Pressure Testing, Commissioning And Decommissioning Procedures - Functional Requirements;

2.10.3. Pressure testing of pipelines – the process

The testing process includes filling the pipeline with an ideal fluid, subjecting the liquid as well as the line to extreme pressure, and verifying that the line holds the pressure over a specified period.

If the line capably holds the pressure, it implies a high integrity gas line and piping system. However, a significant drop in pressure throughout the test indicates line leakage(s) in the system, which requires identifying potential sources and appropriate repairs.

2.10.4. Pressure testing of pipelines – methods

There are several methods of pressure testing gas lines for increased safety in industrial and commercial facilities. However, these methods are categorized into two standard groups: hydraulic and pneumatic.

While hydraulic pressure testing utilizes water, pneumatic leverages the capabilities of non-flammable gas for the pipe pressure tests.

Hydraulic testing remains ideal for higher pressure situations due to its relatively higher degree of safety. Conversely, pneumatic testing remains the most appropriate method for lower pipeline pressure tests. Pressure test shall be a hydrostatic leak test, only where a hydrostatic leak test is impractical, pneumatic leak test may be substitute but it shall be subject to Owner’s prior approval.

2.10.5. Pressure testing of pipelines – preparation – safety

Full care and precaution shall be given by the field management for the safety of the workmen to prevents accidents during the execution of the works. Especially the pneumatic testing involves the hazard due to possible release of energy stored in compressed gas. Therefore, particular care must be taken to minimize the chance of brittle failure of metals and thermoplastics. Pressure testing shall be performed in presence of the Owner's inspector. Pressure testing shall be performed when the weather condition is suitable for inspection.

Prior to test, any piping system to be tested shall be cleaned. Trash and construction debris shall be removed from the piping system by flushing with water or by blowing with air or nitrogen in line with the pressure test medium. All lines shall be completely free of weld slag and other foreign material and shall be reasonably clean. Piping shall be inspected for completeness and conformity to piping drawings and specifications. All required non-destructive testing (NDT) and soap tests of reinforcing rings shall be completed with results satisfactory to Owner. Piping shall be divided into test system by using blinds caps or plugs suitably.

2.10.6. Pressure testing of pipelines – hydrostatic test

As a rule, test shall be hydrostatic, using fresh water or industrial water. The water shall have a suitable corrosion inhibitor which meets Owner approval. Where atmospheric temperature is 0 ºC or below water shall not be used unless water is heated by steam or other heat source, and maintained at temperature of 4ºC or above during the testing. If there is a possibility of damage due to freezing, or if the operating fluid or piping material would be adversely affected by the water, any other suitable liquid such as oil or kerosene may be used.

The hydrostatic test pressure at any point in the system shall be as follows.

- - Test pressure shall not be less than 1 1/2 times the minimum design pressure, but shall not exceed the maximum allowable test pressure for flanges;
- The test pressure shall be corrected to take into account the line temperature;
- The following points shall be taken into account to determine the test pressure
    - The weakest component in the piping system to be tested;
    - In case that the piping system is tested together with equipment having lower test pressure than the system.

Hydrostatic test pressure shall be applied by means of a suitable test pump or other pressure source. After filling the water and purging the air in the piping system to be tested, the pressure shall be increased gradually. maintaining for at least 3 minutes in each step to allow the equalization of strain during test and to check for leaks.

The test pressure shall be maintained for at least one hour prior to starting inspection and long enough to enable inspection of the complete test system.

2.10.7. Pressure testing of pipelines – pneumatic test

As a rule, test shall be pneumatic, using air. The use of other test fluid shall be subject to agreement between Owner. Pneumatic testing shall be made with oil free air. After evacuating all personnel from the test area the system shall be pressurized to 1.7 Bar and held for sufficient time to allow the piping to equalize strains (ten minutes minimum). All joints (threaded, socket welded, butt welded and flanged) shall be preliminary tested for leakage using the test solution.

Pressurize the system gradually to 60% of the indicated test pressure, and hold at that pressure for a sufficient length of time to allow the piping to equalize strains (ten minutes minimum).

Reduce the pressure to 50% of the indicated test pressure and retest all joint for leakage.

Pressurize in steps of not more than 10%, until the indicated test pressure has been reached. The pressure shall be held at each step during pressurizing sequence (to allow the piping to equalize strains) for a period of not less than ten minutes. The indicated test pressure shall be held for a sufficient length of time to permit the testing of all joints, the pressure shall then be reduced to the design pressure before examining for leakage.

Each reinforcing pad (or each segment thereof) and similar attachments shall be tested at a designated test pressure with air, a soap solution shall be used to detect air leaks. A soap solution shall be applied to all screwed, weld and flanged joints undergoing pneumatic test. Where line list or line designation table indicate pneumatic testing, no hydro testing shall be performed.

As pneumatic testing presents special risk due to possible release of energy stored in the compressed gas almost care shall be taken during pressurization and inspection of the system to prevent any danger to personnel or equipment and the chances of a brittle failure of piping.

2.10.8. Pressure testing of pipelines – after pressure test

After completion of the test, the pressure shall be released so as not to endanger personnel or damage equipment.

Welds or portion of welds that leak during test shall be repaired, cutout, rewelded, radiographed (if needed) and line shall be tested again.

2.10.9. Pressure testing of pipelines – draining

After completion of the test, the piping system including equipment to be tested shall be drained as completely as possible. After drainage, remove all temporary blinds and blanks, temporary supports, and temporary testing connections, as per drawings and specifications and reinstall all items such as control valves, relief valves, rupture discs, orifice plates etc., which were removed for test. All drained lines shall be dried after testing by blowing through with dry oil free air. Special care shall be taken that no freezing can occur in winter.

2.10.10. Pressure testing of pipelines – test records

Records shall be made for each piping system during the testing and these records shall include the following items.

A. Extent of testing and specification
B. Identification of piping tested
C. Pressurizing apparatus
D. Test pressure and test duration
E. Test fluid
F. Date of test
G. Approval signature of witness (Owner's and Construction Contractor's representative)
H. Signature of person in charge of testing
I. Applicable remarks concerning defects
J. Water temperature and chloride content
K. Design temperature and pressure

2.10.11. Pressure testing of pipelines – checking for leaks

Prior to initial operation, each piping system shall be leak tested. Leak test of the installed piping system, excluding pressure relieving devices to be used during operation, shall be conducted at a pressure not less than 110% of the design pressure to ensure tightness.

A leak is an undesirable flow of gas or liquid through the wall via an imperfection such as a hole, crack or bad seal. Leaks require a pressure difference to generate the flow; they always flow from higher pressure to lower pressure.

Typically, leaks are thought of as travelling from positive pressure (inside an object) to atmospheric pressure (outside an object)..

What Technique Should Be Used? It is depending on:

- What size is the component and what is it's internal volume?
- What is the leak limit?
- Does it have hidden internal volumes that may affect leak measurements?
- Are the parts clean and dry?
- Is there access to inside or is it a sealed unit?
- Is it rigid or flexible?
- Are parts at ambient temperature?
- What is the surface finish of any sealing surfaces?

Penetration testing: Using penetration liquid the location of a leak can be visible.

Ultrasonic testing: By ultrasonic testing material flow, location of the leakage can be detected.

X-ray measurement: After drying the pipeline an X-ray investigation can reveal the defect.

Air Soap Testing is conducted on storage tanks and their pipelines before the container is set permanently or to maintain road tanker safety. This test is the best chance to determine if welds, joints, and the tank itself do not have any leaks before everything is set underground.

Apply soapy water to the entire hose assembly, including the tank's valve and regulator, using a spray bottle or sponge. Pressurise the system without turning on any appliances. If you see bubbles or smell rotten eggs, you have a leak.

Continuous monitoring: If the pipeline can be fitted with several sensors, a continuous monitoring of possible leakage is also possible.

Control of pressure drop during testing: During the pressure test, the pressure vs. time data is collected, if during the test a significant pressure drop is detected, it can be assumed that a leakage is occurred.

Ultrasonic testing: As a gas flows out of a larger leak, it can generate Ultrasound. This can be detected with ultrasonic microphones. There is also a variation of this in which an ultrasound emitter is placed inside a sealed volume. Both these techniques are used to locate leakage. Ultrasound is used because it dissipates easily and quickly so it gives a good directional capability to locate the leaks.

Ultrasonic Bubble Testing: Ultrasound travels easier through water than air. By detecting the echo from the bubbles, one can measure the distance to where the bubble was detected. This is similar to a sonar ping used in sub sea detection activities.

Thermal Imaging Camera: Some of the latest thermal imaging cameras can be used to detect leakage. This is mostly applied to larger structures. The leaking gas may need to be higher (or lower) in temperature than the majority of the gas in the camera image.

2.10.12. Dimension checks and tolerances in welding

The main scope of dimensional checks and tolerances are: length, angle and shape and position. The tolerances are based on operational experience. There exists four classes of tolerances: A, B, C, D and E, F, G, H. The criteria for selection is, that the technical requirements have to be met. In all cases, the tolerances given in the (relevant) drawing must be used, but tolerance classes may be used instead of specifying them individually. General tolerances are applied to welded parts, sub-assemblies and structures, special requirements may be necessary for complex structures. Dimensional and geometric tolerances shall be applied independently of each other ← this is the principle of independence.

The tolerances on length sizes are:

- the tolerance (t) of the length sizes of a given tolerance class (A, B, C, D) is a function of the nominal size (l).
- within a given tolerance class, as the nominal length size increases, the tolerance increases.
- within a given range of nominal length sizes, the smallest tolerance belongs to tolerance class „A" and the largest tolerance to tolerance class „D".

The tolerances on angular dimensions are:

- the tolerances are given by the length of the shorter angular arm (l)the shorter angular arm may be extended to a specified reference point, which must be marked on the drawing.
- the tolerances are given by the length of the shorter angular arm (l).
- the shorter angular arm may be extended to a specified reference point, which must be marked on the drawing.
- the tolerance (Δα or t) of the angular dimensions of a given tolerance class (A, B, C, D) is a function of the nominal size of the shorter angular arm.
- the tolerance may be given in degrees and minutes (Δα).
- the tolerance may be given in mm/m, calculated and rounded off (t), corresponding to the tangent of the overall tolerance.
- within a given tolerance class, the value of the tolerance (Δα or t) decreases as the nominal size of the shorter angular stem increases.
- within a given range of nominal shorter angular lengths, the smallest tolerance (Δα or t) belongs to tolerance class A and the largest tolerance (Δα or t) belongs to tolerance class D.

The tolerance of straightness, flatness and parallelism:

- the tolerance (t) for a given tolerance class (E, F, G, H) is a function of the nominal size (l).
- for flatness and parallelism, the longer side of the surface is decisive.
- within a given tolerance class, the tolerance increases with increasing nominal size.
- within a given range of nominal sizes, the smallest tolerance belongs to tolerance class E and the largest tolerance to tolerance class H.

2.10.13. Dimensional measuring tools

Theres exists different kinds of dimensional measuring tools:

- Calipers
- Micrometers
- Dial Indicators
- Gages
- Borescopes
- Force measurement devices
- Hardness, surface testers
- Rulers, Protractors, Squares
- Vision and optical systems, thickness gauges

2.11. Qualification and certification of NDT personnel

Regarding the qualifications and certification of personnel the following definitions apply:

Qualification: Demonstration of physical attributes, knowledge, skill, training, and experience required to perform NDT tasks effectively.

Certification: Procedure used by the certification body to verify fulfillment of qualification requirements for a specific method, level, and sector, leading to the issuance of a certificate. Please note that obtaining a certificate does not grant authorization to operate; this authority is granted solely by the employer.

Operating Authorization: A written statement provided by the employer, based on certification scope, authorizing an individual to perform defined tasks. This authorization might require job-specific training.

NDT Method: A discipline that applies physical principles in non-destructive testing, such as Ultrasonic Testing.

NDT Technique: A specific approach to using an NDT method, like the Ultrasonic Immersion Technique.

NDT Procedure: A written description of essential parameters and precautions for applying an NDT technique to a specific test. It follows established standards, codes, or specifications and can involve multiple NDT methods or techniques.

NDT Instruction: A written guide detailing precise steps for testing according to standards, codes, specifications, or NDT procedures.

The key guidelines for qualifying and certifying NDT personnel include the ISO 9712 standard in Europe and the ASNT SNT-TC-1A recommendation in the USA.

Nowadays, the primary guideline is the International Standard ISO 9712, which blends European and American approaches.

Certification levels include:

- Level 1: Competence to perform NDT under supervision
- Level 2: Competence to perform NDT per established procedures
- Level 3: Competence to direct NDT operations and validate procedures

Qualification involves training, experience, and passing exams. The ISO scheme includes Basic and Main Method Exams. The ASNT scheme also features exams and practical assessments.

Renewal and recertification vary between ISO and ASNT standards, involving visual acuity tests, work activity evidence, and practical or written exams.

These standards provide a solid framework for ensuring NDT personnel's competence and maintaining high-quality testing practices.

In both the ISO and ASNT standards, qualification and certification are crucial steps to ensure NDT personnel possess the necessary skills and knowledge. The training, experience, and examination processes outlined in these standards help maintain the quality and reliability of non-destructive testing.

The ISO 9712 standard emphasizes the importance of training content that aligns with established syllabuses such as ICNT WH 16-85 to 21-85 for Level 1 and Level 2. Similarly, the ASNT SNT-TC-1A standard refers to ANSI/ASNT CP-189:2001 as a basis for training content.

For Level 1 and Level 2 candidates, documentary evidence of completed training is essential, and the required hours vary based on NDT level, method, and qualification scheme.

Visual acuity and color vision are also assessed, with specific requirements based on the standard used—ISO 9712 or SNT-TC-1A.

The examination process varies based on the certification level. Level 1 and Level 2 candidates face theoretical and practical assessments, with Level 2 candidates additionally preparing NDT instructions for Level 1 personnel.

Level 3 candidates undergo Basic and Main Method Examinations. These examinations assess their knowledge of materials, process technology, qualification systems, test methods, and more.

Renewal and recertification processes differ between ISO and ASNT standards. ISO offers renewal and recertification based on visual acuity, work activity, and examinations. ASNT requires evidence of visual acuity, work activity, or successful examinations for renewal.

Ultimately, both standards prioritize ensuring that NDT personnel maintain their expertise and stay up-to-date with industry practices. By adhering to these standards, organizations can ensure the continued competency of their NDT workforce and maintain the quality of non-destructive testing processes.

Maintaining the qualifications and certifications of NDT personnel is vital for ensuring the accuracy and reliability of non-destructive testing results. The emphasis on continuing education and practical assessments ensures that professionals stay current with industry advancements and maintain their skills.

ISO's renewal and recertification approach, involving visual acuity, work activity, and examinations, allows certified individuals to validate their competence periodically. This process guarantees that certified individuals are still capable of performing their duties effectively.

On the other hand, ASNT's renewal process, which relies on visual acuity, work activity, and successful examinations, offers a comprehensive evaluation of an individual's continued competence. This approach emphasizes a thorough review to ensure NDT personnel's capabilities are maintained over time.

In both standards, the recertification process for Level 3 personnel involves more stringent requirements, acknowledging their responsibilities in directing NDT operations and ensuring a high level of expertise.

Overall, these standards play a critical role in shaping the NDT industry by establishing rigorous criteria for qualification, certification, and renewal. Organizations that adhere to these standards benefit from having a skilled and knowledgeable workforce that can consistently deliver accurate and reliable non-destructive testing results. This, in turn, contributes to the overall safety and integrity of various industries and the products they produce.

The process of qualifying, certifying, and maintaining NDT personnel's competence is a cornerstone of ensuring the quality and safety of various industries. Both the ISO 9712 and ASNT SNT-TC-1A standards provide a structured framework that promotes consistency, reliability, and professionalism in non-destructive testing practices.

By establishing clear guidelines for training, experience, and examinations, these standards empower individuals to develop a solid foundation in NDT principles and techniques. The focus on theoretical knowledge, practical skills, and understanding of codes, standards, and procedures prepares NDT personnel to effectively identify defects and anomalies in materials and products.

As technology and industries evolve, these standards offer flexibility through renewal and recertification processes. These processes acknowledge the importance of continuous learning, encouraging NDT professionals to stay updated with the latest methodologies and advancements in their field.

Moreover, the distinction between different certification levels, from Level 1 to Level 3, ensures that individuals are assigned tasks according to their demonstrated competency. Level 1 individuals work under supervision, Level 2 personnel perform NDT using established procedures, and Level 3 experts direct and oversee NDT operations.

By adhering to these standards, organizations demonstrate their commitment to quality assurance and safety. Clients and industries can rely on the expertise of certified NDT personnel to deliver accurate and reliable assessments of materials and components.

In conclusion, the qualification, certification, and recertification processes outlined by ISO 9712 and ASNT SNT-TC-1A are crucial for maintaining the integrity of non-destructive testing practices. They serve as a foundation for skilled professionals to contribute to safer, more reliable products and structures across various industries.

2.12. Documents for quality control

2.12.1. The role of the Welding Inspector on Documents for quality control

The welding inspector's role may change based on applicable standards and specifications. Considering the EWF/IIW guideline as a reference document, or taking into consideration that this is an industrial best practice, we can excerpt their role for the Welding inspectors as referred to documents for quality control, as follows:

The inspector's role begins well before welding starts, continues during the welding operation, involves action after welding is completed, and is finished only when the results are properly reported. As part of the quality system, inspection activities are defined in an inspection and test plan, which clearly describes what is required. The inspector is frequently responsible for producing documents that ensure traceability of the components and related fabricating action.

The activities of a Welding Inspector can be referred to:

- Begin well before welding starts
- Continue during the welding operation,
- Involves action after welding is completed,
- finished only when the results are properly reported.

As part of the quality system, inspection activities are defined in an inspection and test plan, which clearly describes what is required. The inspector is frequently responsible for producing documents that ensure traceability of the components and related fabricating action

Still from the EWF/IIW guideline, the list of typical duties of the welding inspectors are:

- Interpretation of drawings and specifications;
- Verification of procedure (WPS) and welder or welding operator qualifications;
- Verifying the application of approved welding procedures;
- Selection of production test samples;
- Interpretation of test results;
- Preparation of reports and keeping of records;
- Preparation of inspection procedures;
- Check the correct application of NDT methods.

All these require that the Welding inspector has access to and knowledge of production documents.

2.12.2. Inspection and testing plan

Inspection and Test Plans are a common tool used in welding manufacturing, considering the extent of control required before, during and after welding. Clearly, they see the welding inspector heavily involved.

Inspection and Test plans are also sometimes referred to as Quality inspection plans.

They are designed to set out critical control points or 'hold points' at various stages within the manufacturing process. Each control point is a scheduled inspection or verification activity where it is made sure that things are progressing according to specifications or standards, and possibly perform corrective actions.

As most are probably familiar with ISO 9001, anything related with quality is considered in the Standard. As such, Inspection and Test Plans are used to control quality and are one way to satisfy the requirements of the ISO 9001 standard related to the control of production and service provision. *Clause 8.5.1* Control of production and service provision states, at a certain point, "the implementation of monitoring and measurement activities at appropriate stages to verify that criteria for control of processes or outputs, and acceptable criteria for products and services, have been met; …"

Clause 8.6 Release of products and services states The organization shall implement planned arrangements, at appropriate stages, to verify that the product and service requirements have been met.

2.12.3. Drafting an Inspection and Testing Plan

The goal of an Inspection & Test Plan is to document the plan for managing the quality control and assurance of a particular element and to record activities performed. It provides information on the requirements to be met, an overview of the method(s) to be used, responsibilities of relevant parties, and documentary evidence to be provided to verify compliance. As such, it deals with the quality aspects of the product and the manufacturing process.

The Inspection/test activities may be under the responsibility of different parties involved:

- The manufacturer
- The inspection authority
- The customer or its representative
- An independent third party

Welding Inspectors are therefore the typical individuals involved in the process.

An ITP is typically composed of the following elements:

- Scope, defining the area of applicability
- References, with Standards, specifications, drawings and any other reference material
- Control points, following the stages of the manufacturing process and the control points for each stage.
- Each section must be read carefully when managing or working with an ITP, to avoid mistakes and or misinterpretations.

Table 1

TEST		Checked (date)	Signature of the inspector	Reference report
Tests before welding operations	**Reference procedure**			
Suitability and validity of welders qualification certificates				
Suitability of welding procedure specification				
Identity of parent material				
Identity of welding consumables				
Joint preparation (e.g. Shape and dimensions)				
Fit-up, jigging and tacking				
Special requirements in the welding procedure specification (e.g. Prevention of distortion)				
Arrangement for any production test				
Suitability of working conditions for welding, including environment				

Table 1, 2 and 3 show a tipica structure for an ITP. The content is based on ISO 3834, as the standard defines the items to verify for a proper management of the welding fabrication Process.

As already mentioned, for each item of the ITP the following information should be included:

- Reference procedure or standard
- Date when this was Checked
- Signature of the Inspector, reference report, if needed.

Further columns may be added, and a common one is dealing with phases of intervention, with reference to the Manufacturer, the Customer and the Third Party. A further slide will deal with this.

This section of the ITP deals with test that are commonly taken before welding operations are performed. The items are possibly expanded depending on the complexity of the construction. It is essential to realize that this is an example, and some items in the list may not be included, and others not in the list may be added.

Before welding is performed, typical test include:

- Welder qualifications
- Welding procedure Specifications
- Identification of base materials, to ensure that they are consistent with the drawings and the material Certificates; sometimes this involves also traceability
- Identification of consumables, to ensure that they are consistent with the drawings and the material Certificates; sometimes this involves also traceability
- Joint preparations, to be consistent with drawings and WPS
- Fit up, used jigs and fixturing, or tacking operations. Particularly, tacking may be critical on low alloyed and High alloyed steels and some non ferrous materials.
- Special requirements for prevention of distortion such as joint welding sequences or straightening devices
- Specific requirements for production tests, as concerns intermediate NDT or production specimens

Table 2

TEST		Checked (date)	Signature of the inspector	Reference report
Tests during welding operations	Reference procedure			
Preheating / interpass temperature				
Welding parameters				
Cleaning and shape of runs and layers of weld metal;				
Back gouging;				
Welding sequence;				
Correct use and handling of welding consumables;				
Control of distortion;				
Dimensional check				

This section of the ITP deals with tests that are common During welding operations are performed. The items are possibly expanded depending on the complexity of the construction. Again, it is essential to realize that this is an example, and some items in the list may not be included, and others not in the list may be added.

Before welding is performed, typical tests include:

- Preheating and interpass temperatures. These may be recorded on a report, or it may be the IWI to perform it. Clearly, they should be in accordance with the applicable WPS and other specifications
- Welded parameters, as in the former, may be recorded on a report, or it may be the IWI to perform it and they should be in accordance with the applicable WPS and other specifications
- Cleaning, the shape of runs and layers, as well as back gouging and welding sequences are not always well presented in the applicable WPS. Specific requirements may be written in other specifications. In any case, welders and Inspectors should use good technical sense, by keeping in mind their specific role and authority.
- Weld sequence is another item that is not always required to be taken care of. In this case, Specific requirements may be written in other specifications. In any case, welders and Inspectors should use good technical sense, by keeping in mind their specific role and authority.
- Use and handling of welding consumables in an essential point in the manufacturing process, keeping in mind the possible effect on cracking and welding defects in general. Unless otherwise specified, requirements may be found in the manufacturer specifications that should be considered as mandatory.
- Weld sequence is another item that is not always required to be taken care of. In this case, Specific requirements may be written in other specifications. In any case, welders and Inspectors should use good technical sense, by keeping in mind their specific role and authority.

- Finally, a dimensional check may be required whenever the dimensions of the product are specified. This is essential in consideration of the effect of welding o distorsion.

Table 3

TEST		Checked (date)	Signature of the inspector	Reference report
Tests after welding operations	**Reference procedure**			
Compliance with acceptance criteria for Visual Testing				
Compliance with acceptance criteria for other NDT examinations (e.g. Radiographic or Ultrasonic Testing)				
Compliance for destructive testing (when applicable)				
Results and records of post-welding operations (e.g. PWHT)				
Dimensional checking.				

This section of the ITP deals with tests that are common During welding operations are performed.

Tests after welding are more common and include the performance of NDT and verification of applicable certificates. In some occasions, Destructive testing may be performed as well on scraps or on spot.

Whenever PWHT is performed, this requires special attention as it is, by itself, a special process. It is important to consider that the applicable WPS may not provide all the necessary information to the manufacturer and the inspector. When the construction is complex, additional requirements or specifications may apply.

However, table 3 be may possibly expanded depending on the complexity of the construction. Again, it is essential to realize that this is an example, and some items in the list may not be included, and others not in the list may be added.

2.12.3.1. Phases of intervention, with reference to the Manufacturer, the Customer and the Third Party

Sometimes inspection and testing plans have a specific nomenclature to detail the Phases of intervention, with reference to the Manufacturer, the Customer and the Third Party. Commonly these are reported on a column and refer to the legenda reported in the slide.

- H stands for Hold point, a binding phase.
- W stands for Witnessed activity; the activity may be witnessed by the quality department of the manufacturer or an inspector of the customer or a third party;
- C stands for Certification, it a presence activity with certificate issuance
- R stands for review of Documents and certificates,
- A stands for Document approval before progressing,
- P stands for Presence without certificate issuance
- SW stands for Spot witnessing, an activity attended on spot.

2.12.3.2. Drafting an Inspection and Testing Plan

Finally, the parties or persons involved in the inspection activity should be specified. Very often this information is presented with one column dedicated to each party/person. Codes are usually developed which summarize the type of test and level of involvement.

The first element, often neglected, is the scope. It should include A simple summary of the scope of the works applicable to the ITP, but it may also be useful to specify what is not included to provide additional clarification for anyone reading the document.

The second element is applicable references. Most people associate the criteria for the works with the drawings and specifications. Although these are likely to be the most significant sources of information, there are others and it is important to consider them. Drawings and specifications often refer to and require compliance with other documentation. Therefore, the following may be a list of relevant items to consider although this is not exhaustive:

- Drawings (including notes on the drawings)
- Design specifications
- International Standards and other standards
- Manufacturers' or contractor's requirements, or contractual requirements
- Planning conditions
- Legislative requirements

When producing an ITP is it often useful to think about the stages of delivery in chronological order and assign the assurance activity items to each relevant stage as listed in this slide.

The first stage is manufacturing. There may be items which need to be inspected & witnessed before the manufacturing activities start. For example, it would be prudent to undertake a check to make sure that the design is suitably developed. There may be a requirement for design prior to any manufacture or site works, e.g. structural steel fabrication drawings. This may require drawing approvals, checking of calculations etc. There may also be a requirement for the submission and approval of samples or mock-ups to verify design requirements. These should be referenced where appropriate. Additionally, the Risk Assessment / Method Statements may require approval and a check might need to be completed to ensure persons undertaking the works are suitably competent.

Material Conformity is an essential stage to ensure that materials are compliant. Sometimes, materials may need a formal approval. IN addition, storage is also a critical point, both for base and filler metals. Review of materials certificates or test reports falls in this section of the ITP.

In cases where a product is manufactured away from the site, appropriate consideration should be given to how the principal contractor or contractor will ensure and demonstrate the product is compliant. Once the product arrives on site, if incorrect, it will be too late and may have significant implications for the programme. Therefore, it is important to consider how compliance with this work will be assured. For example, it may be necessary to visit the factory, undertake Factory Acceptance Tests, or request specific assurance documentation. In some situations, a completely separate ITP may be produced by the principal contractor for an element of the work which is manufactured off-site. As an alternative, a Certificate of Conformity may suffice as a means to demonstrate compliance.

Clearly, in most cases, the manufacturing section of the ITP will constitute the most significant proportion by volume of the ITP. This section will specify how the physical construction works on site will be inspected and tested. Typically, in the case of welding manufacturing, this is again sub-divided in sections, that may also include intermediate tests.

The section on final tests and commissioning usually specifies the testing of the completed works and is often most significant for the final compliance of the manufactured goods. These may include pressure testing, overload testing, etc..

Pre-construction or erection activities include activities that may still need to be undertaken post-completion. For example, products may also have an inspection and handover process to the client. One of the most important elements of this stage may be how the works are to be protected in readiness for works by follow-on trades.

This section of the drafting will most likely take the most time and effort to complete. The outcome of these steps will be to have listed on the ITP all quality assurance activities relevant to the specified scope of the manufacturing, as listed in section 1.

To determine the items which need to be listed on the ITP, the most straightforward way is probably to go through each of the criteria documents in turn in a systematic manner and pick out the items which need to be listed on the ITP.

It is then necessary to consider each item in turn and provide details of how the criteria will be met, the evidence that will be produced, who should be involved in the assurance activity and finally the type of inspection or test involved.

There is no standard on how an ITP should be drafted, but this section is in general a table with columns, each dedicated to a piece of information. However, each organization develops their own preferred template and it may also happen that a customer requires the use of a particular template. The commonly agreed best practice is that the following information is listed, typically one for each column.

The first is a description of the Assurance Activity, followed by the details of the criteria. It is useful (for future reference) to include full details of the exact source document which should also include the revision number (as revisions of the same document could differ) and location within the document (e.g. specification clause number). It may be useful to list just the specific criteria to be met, when applicable. These may be acceptance criteria, as an example.

A description of the activity that will be undertaken to ensure compliance should then be provided. Despite this is probably considered the main information, the other columns are essential as well.

The following information is the detail of the evidence to demonstrate compliance and information on where it may be tracked or referenced. This is an essential point for the future users of the information provided by the ITP.

It is useful to include information on who is responsible for ensuring the assurance activity is completed satisfactorily and, possibly the resources required. The last information is very important from a Human Resources, Tools and equipment management perspective.

Finally, the parties or persons involved in the inspection activity should be specified. Very often this information is presented with one column dedicated to each party/person. Codes are usually developed which summarize the type of test and level of involvement. As an example

2.12.4. Welded Joint traceability

Weld traceability is an essential part of the quality records for welded constructions. The goal is to achieve the ability to retrieve information for each weld from records.

Welds need to be identified and records of the performed welds maintained. Identification may be achieved by:

- Marking each different weld on drawings
- Referring to on the Inspection and Testing Plans
- Some specifications require to put stamped marks on welds, identifying the specific weld type
- Welder performance records, where welders indicate the activities performed
- And any other possible means that helps in achieving the goal

The extent of the traceability is a requirement of the applicable standard, procedures or specifications

The following aspects may be recorded, depending on the applicable requirements

- weld procedure used,
- identification of the welder,
- date when welded,
- unique identification number of the weld,
- drawing number,
- weld consumable batch number,
- materials welded,
- NDE / NDT report numbers,
- inspector identification,
- inspection results.

Traceability may be important for several reasons:

- To track performance of welders
- To track performance of WPSs
- Tao avoid repetition of mistakes
- To back track consequence of the failure of a welder, equipment, WPS or other manufacturing issues
- To back-track other issues in production or in service

2.12.5. Use of Drawings and how to read them

A technical drawing is a detailed, precise diagram or plan that conveys information about how an object functions or is constructed. Even if precise standards apply on how to draw constructions, for example regarding the meaning of lines, dashing, sections, etc,, the amount of information covered in a drawing is not standard. For this reason the Drawing may be complemented by additional sheets providing the necessary information.

As discussed in different sections of the course, different standards may apply on a global basis for the representation of welds on a drawing.

From an inspection perspective, drawings are needed to find useful information to perform the inspection tasks, such as for example, Joint identifications, base materials, Construction phases and further as depending on the level of detail provided.

Figure 1 is a simple example of a technical drawing for a pressure vessel.

Figure 1

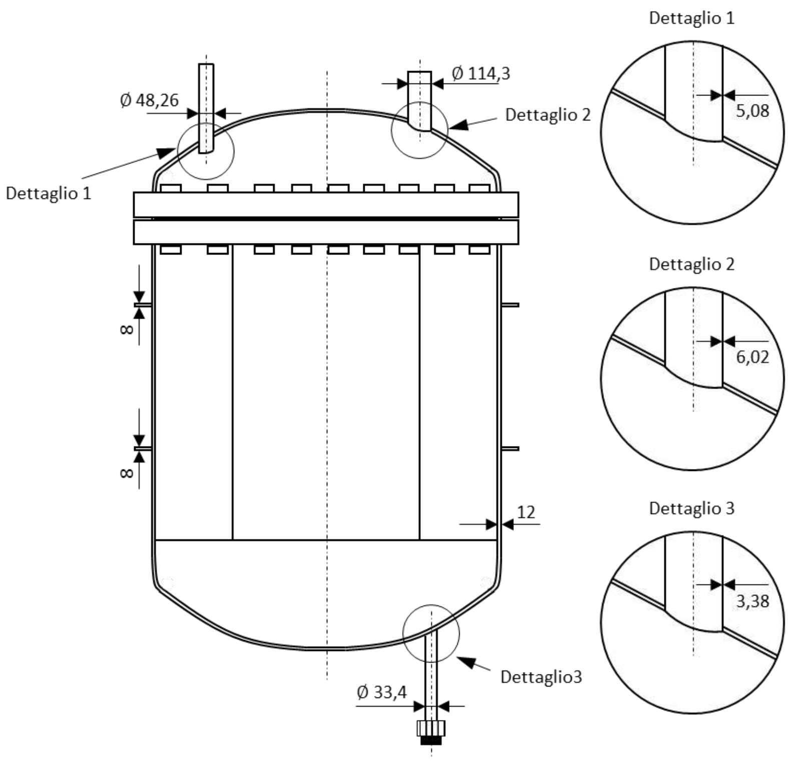


Table 4

Component	Material	Thickness [mm]	Diameter [mm]
Vessel body	EN 10028-3 P355N	12,00	NA
Stiffners	EN 10028-3 P355N	8,00	NA
Nozzle (Detail 1)	EN 10216-3 P355NL1	5,08	48,26
Nozzle (Detail 2)	EN 10216-3 P355NL1	6,02	114,30
Nozzle (Detail 3)	EN 10216-3 P355NL1	3,38	33,40

In this case, it just provides a general overview of the product as it is very simple. The table provided (table 4) may be included in the sheet of the drawing or a separate document. However, the two combined do not offer enough information about the joints and a separate document will be needed.

2.12.6. Material Test Certificates

The Material Test Certificates or material Tests reports Report is a document that verifies a material's chemical and physical properties in accordance with a given standard or specification.

The scope is to accompany a given material and testify that the delivered material is exactly what required.

The content is :

- detailed information on the material's composition, including the type, grade, and specification,
- results of various tests the material was subjected to, such as tensile strength, yield strength and more.

EN 10204 defines the different types of control documents provided to the buyer, as agreed at the time of the order for the supply of metal products.

The use of EN 10204 documents is a requirement of the applicable manufacturing standard, specification or requirement
The standard must be used in conjunction with the standards specifying the general technical conditions of supply. The material designation must be provided unambiguously and completely (e.g. EN 10025-2 S355J2 + N)

Based on the extent of the testing performed and the issuer, the document can be a simple declaration of compliance with the order or a test report, issued by the manufacturer.

When the level of control rises, an inspection certificate may be required, and this may be of two different levels:

- Inspection certificate 3.1 (in accordance with EN 10204), or
- Inspection certificate 3.2 (in accordance with EN 10204).

Table 5

Document	Content	Issued by
Declaration of compliance with the order	Declaration of conformity to the order	Manufacturer
Test report	Declaration of conformity to the order, indicating the results of the non-specific check	Manufacturer
Inspection certificate 3.1	Declaration of conformity to the order, indicating the results of the specific check	Authorised manufacturer's representative for inspection, independent of the manufacturing department
Inspection certificate 3.2	Declaration of conformity to the order, indicating the results of the specific check	Representative of the authorized manufacturer for inspection, independent of the manufacturing department and, jointly, representative of the authorized purchaser for the inspection or inspector designated by official regulations

A Declaration of compliance with the order, sometimes referred to as Document 2.1, is a Declaration of conformity to the order and is simply issued by the manufacturer.

A Test Report is a Declaration of conformity to the order, indicating the results of the non-specific check is Declaration of conformity to the order, indicating the results of test performed on the same production line, but not on the specific batch. It is still issued by the Manufacturer, as example by the production department.

An Inspection Certificate 3.1 is a Declaration of conformity to the order, indicating the results of the specific check, meaning tests performed on the delivered batch. It is issued by an authorized manufacturer's representative for inspection, independent of the manufacturing department, typically the quality department of the manufacturer.

The Inspection certificate 3.2 is the highest level, and hence most costly:. it is still a Declaration of conformity to the order, indicating the results of the specific check, but the issuer is a Representative of the authorized manufacturer for inspection, independent of the manufacturing department and, jointly, representative of the authorized purchaser for the inspection or inspector designated by official regulations

The Material Test Certificates or Material Tests reports are documents that verify a material's chemical and physical properties in accordance with a given standard or specification.

The scope is to accompany a given material and testify that the delivered material is exactly what required.

The content is :

- detailed information on the material's composition, including the type, grade, and specification,
- results of various tests the material was subjected to, such as tensile strength, yield strength and more.

The primary goal of a material test certificate is to improve transparency and traceability throughout the manufacturing process, as it refers to a given batch number.

By examining the certificate, it is possible to trace the production record of the factory and the testing results of the specific product.

By tracking the batch number throughout different phases of production, it si possible to retrieve information at any time during the manufacturing or life of the product.

For this specific purpose, recording of Material Test Certificates or reports may be required by the ITP.

Whenever dealing with a Material Test Certificate / Report, a welding inspector must take care of some further issues.

Smaller factories may not have the testing capability to perform the standard or the required test. They may issue certificates without proper testing. This may bring to rejection of the certificate.

Trading companies may intentionally conceal the original manufacturer of the materials to prevent clients from knowing their sources. They may use their own company name to replace the actual manufacturer's information. This may be incorrect, as it breaks the traceability chain.

Suppliers may sometimes issue material test certificates that contain inaccurate or misleading information or do not conform with the materials of the order. This requires proper attention to possibly bring to rejection or request for integration of testing, if possible.

Clients may not fully understand the meaning and significance of the report, making it difficult for them to recognize the accuracy and quality of the report.

Some material test reports suppliers may not contain a stamp or signature from the quality control department and should therefore be considered invalid.

2.12.7. Non Destructive Testing Report Review

The selection of non-destructive testing (NDT) method(s) for welded joints is a complex task.

The general principle is that the recorded information should allow the completion of the same testing and obtain the same results. That requires detailed information on

- the inspection technique used;
- the client's information, codes and specifications used for the evaluation;
- the equipment used;
- The NDT operator that performed the task
- detailed results of any imperfections recorded at a minimum.

Even if the full report is very important, it should be noted that item 2 "client's information, codes and specifications used for the evaluation" is properly considered as the highest priority, as it impacts the overall validity of the report. Acceptance criteria, extension of testing and applicable techniques may vary significantly based on the specifications to be used for the construction.

The operator is another very important information, as together with the NDT equipment may be significant for the traceability.

2.12.8. Destructive Testing Report Review

Destructive testing reports may vary significantly depending on the test used. It can refer to mechanical, chemical or other testing.

Whenever an inspector is reviewing testing reports, the following aspects should be properly considered:

- The client's information, codes and specifications used for the evaluation. As always, it is very important to verify consistency between the report and the requirements for the production.
- Specimen size and tolerances, as the results of testing may vary significantly and not all the properties are independent of the size of the specimen.
- Sample collection area, when applicable (e.g. WM, HAZ, longitudinal/transversal, etc.); this is very important again, as results may vary significantly. One typical example is impact testing, where longitudinal or transversal specimens may have different results.
- Testing parameters (Temperature, speed of loading, etc.). These are essential parameters in mechanical testing, as metal properties are temperature-dependent.
- The equipment used, may be very significant for traceability. In some specifications, the accreditation or certification of the equipment may also be a requirement
- Detailed results of the testing, including a detailed report of reference parameters.

2.12.9. WPS Review

Welding Procedure Specifications are essential documents in the Welding inspection. A considerable amount of time has been spent in other modules to define the content and role of a WPS in production. WPSs are an essential task in the documental review performed by a Welding inspector, being the main purpose:

- To verify possible technical errors and inconsistencies. Processes, parameters and heat input, position and materials need to be consistent with the manufacturing conditions and building steps.
- To verify consistency with the production requirements, such as applicable standards, specifications or design requirements
- To cross-reference to welders' qualifications, as each WPS need to be consistent with the welder qualifications. In other words, a WPS is useless if there is no welder qualified to use it.
- To verify the content falls within the qualified range of the supporting WPQR. This can be easily done by checking the qualified range in the supporting WPQR.

Manufacturers list applicable documents for production in specific folders. Commonly, as far as wedling is concerned, these include a welding book.

Essential elements of a welding book (basic) are: **Cover page and scope with applicable references;**

To these are often added additional elements that make the welding book more complete and exhaustive. Among them:

- WPQR to support production WPS;
- extract of the plan of process qualifications and welders;
- list and follow-up of NDTs performed;
- list and follow-up of any repairs planned.

2.12.10. WPQR Review

Welding Procedure Qualification Records are essential documents in the Welding inspection. A considerable amount of time has been spent in other modules to define the content and role of a WPQRS in production. However, the way to approach WPQRs may be different depending on the tasks assigned. In the IIW/EWF training, the level is consistent with the qualification level.

A simple review is done to verify the application standard and possible further requirements are properly considered. The information is typically included in the forts page of the Record. Commonly this task may be assigned to a welding Inspector at the Basic level.

An in-depth review requires the verification of the Record in its entirety, and this may be assigned to an Inspector at the Standard or Comprehensive Level. One of the most frequently assessed points is the correspondence between Recoded parameters and the qualified range. This requires cross-referencing between the parameters as recorded and the reference standards. The other area is to verify possible supporting documents, such as material and testing certificates to verify they were corrected in accordance with the applicable requirements and the acceptability of the results.

These activities take time on the first attempt but will take less time once the welding Inspector is practised. For this reason, a booklet of supporting documents was made available for this lesson.

2.13. Economics in Welding Inspection

In the realm of welding, numerous economic factors exert their influence, necessitating a comprehensive approach that begins with the design phase of production.

Regarding filler material, determining its quantity hinges on an analysis of groove geometry, the excess weld metal (often estimated at 2% of nominal thickness), and the density of the metal to be deposited. This parameter significantly impacts the final product cost.

The sketch provides insights: "g" signifies the gap, "s" represents the shoulder, and α signifies the angle of the chamfer aperture.

To accurately assess deposited material quantity, the Welding Coordinator must select the welding process and the applicable current. Process evaluation is commonly grounded in experimental data, while operating factor assessment gauges automation levels.

The cost breakdown for SMAW welding comprises filler material volume and electric energy completion time (Ttot). Completion time is divided into preparation (a), run time (c), and electrode time using the formula: Ttot = a + b x nruns + c x nelectrodes. Here, "nrun" denotes the runs required for completion, and "nelettrodes" indicates the electrodes needed.

Preparation time hinges on various aspects:

- Equipment: preparation and verification
    - Fetching tools (grinder, chipper, personal protective equipment, etc...)
    - Electric generator displacement, plug-in and verification of main functions
    - Electrode holder clamp verification
- Miscellaneous preparation (Working instructions, welding maps, WPS)
    - Bevel preparation (oxyfuel cutting, plasma cutting, bevel grinding, etc…)
    - Choice of electrodes (rutile, cellulosic, basic, high-efficiency electrodes, etc…)
    - Electric generator set up
    - Working piece orientation (mechanical positioning device, etc…)

Slag removal impacts production times, varying with factors like geometrical bevel preparation, joint type, electrode diameter, and efficiency.

The electrode's timing is characterized by three parameters: Fusion time (Current Density, Electrode Diameter, Welding Position), Changing Electrode Time, and Welder "Duty Cycle" (Welding Position, Workplace Ergonomics).

Balancing economical preparation and positions without compromising joint quality is pivotal, as repair times can be costly.

For accurate electrode supply cost estimation, key parameters include density, electrode diameter, and electrode efficiency. Costs also encompass welder salaries and additional overhead.

Labor costs hinge on hourly welder rates, which may vary across plants. Overhead costs encompass services, taxes, facilities maintenance, and equipment depreciation.

The Operator Factor reflects the percentage of welding time amid setup, preheating, slag removal, and electrode changes. This factor for the process is relatively low, ranging between 20% to 50%.

Electrode deposition rates impact labor and overhead costs, influencing overall productivity.

Submerged Arc Welding (SAW) involves an electric arc beneath a flux, creating a protective environment for the arc, molten pool, and solidification, resulting in slag that shields the bead from oxidation. SAW is typically in Fully Mechanized or Partially Mechanized modes and is limited to flat or horizontal-fillet positions.

Deposition rates in SAW can reach 45kg/h (contrasting with 5kg/h in SMAW), and productivity can be enhanced via multiple wires.

Process specifics encompass Welding Speed, Welding Current, Arc Voltage, Component Dimension, and Positioning. The deposition rate graph for SAW highlights proportionality based on diameter and power source usage.

Cost breakdown includes Consumables (Filler Material + Flux, evaluated as MFlux1.3*MFiller Material) and Electric Energy Consumption (4-5 kWh/kg).

Equipment depreciation varies, negligible for standard components and significant for specialized applications.

Execution time hinges on Arc Time, Fitting Times, and intermittent work periods. Positioning Time varies based on component weight, possibly requiring cranes. Process Time encompasses setup and wire/flux change, with these operations occurring roughly every 4 to 6 minutes.

Flux preparation time is significant, with the filling process around 3 minutes due to market experience.

Preparing wire is crucial, calculated based on deposited material mass and bundle mass, with a change time of approximately 10 minutes.

The completion time can be estimated such as:

$$T_{tot}=R*(A+B+C*P+D)$$

Where:

A: it is the arc time

B: it is the total time to maneuver the component

C: it is the time needed to place the welding head on place per run

P: it is the number of runs

D: it is the total amount of time needed to change the wire and fill the flux tank

where "R" represents dead and rest times (usually around 1.1 or 1.2).

Gas Metal Arc Welding (GMAW) evaluation requires consideration of wire diameter, shielded gas, base material, and ampere value. The welding process's efficiency is intertwined with transfer modes, influencing arc time.

Gas consumption and costs assume 0.3 – 0.4 m3/h for every 100 A.

Gas Tungsten Arc Welding (GTAW) finds application on thin, dissimilar, and non-ferrous metals due to its capabilities. It's chosen for its attributes over cost-efficiency.

GTAW with Tungsten electrodes sees electrode replacement based on welder skills and welding current. Approximating cost, the electrode equals about 4% of shielding gas cost.

Comparing SMAW, GMAW (Semi and Auto), FCAW, and SAW reveals shielded electrode process's relative expense, despite its versatile aspects. Now we have enough data to make a summary of the main features, in terms of costs, between the traditional welding techniques and most widely used in production.

«SMAW»: Flexible, it allows welding in all positions; simple and transportable equipment. Many filler materials are available, optimized for different characteristics. It has low performance and requires the removal of slag.

«GMAW»: Quite flexible, it requires complex equipment (wire feeder, gas systems, pulsed...) and welding in position can be difficult. The removal of the slag is not necessary. It is more efficient than SMAW and can be easily mechanized and/or robotized.

«FCAW»: Quite flexible, has good productivity and allows welding in position without particular precautions. Some types of wire do NOT require shielding gases. Like the GMAW can be easily mechanized. It may be necessary to remove the slag.

«SAW»: Weld only flat position, with high productivity though. Huge but relatively simple equipment is needed. The final quality is excellent. Removal of excess flow and slag is necessary.

Understanding the relevance of Non-Destructive Testing (NDT) in welding quality assurance relies on:

- NDT's role in production timing and cost calculation
- Visual Testing's speed but limited sensitivity
- MPI's execution time, non-applicability to non-ferromagnetic materials, and equipment requirements
- Dye Penetrant Testing's cost-effectiveness and considerations
- Radiographic Examination's cost variations based on joint transportability, influenced by thickness, film type, and isotope
- Ultrasonic Examination's standard and advanced methods, influenced by geometry and operator skill

Regardless of the NDT method, personnel training and qualification must be factored in.

The effective implementation of non-destructive tests (NDT) plays a pivotal role in ensuring the quality and integrity of welded joints. These assessments are essential for maintaining industry standards and ensuring safe, reliable products.

Visual Testing remains the fastest method but possesses limited sensitivity, making it most suitable for detecting surface-level operational defects.

Magnetic Particle Inspection (MPI) is another valuable NDT method. Its estimated execution time is around 6 meters per hour. However, it's not applicable to non-ferromagnetic materials. The procedure involves specific equipment such as an electromagnet, yoke, and tips. Choosing the appropriate type of magnetic particle requires careful consideration.

Dye Penetrant Testing is recognized for its cost-effectiveness and simplicity. With an estimated execution time of 3 meters per hour, it necessitates surface preparation and a suitable dwell time for the liquid used. It's ideal for detecting surface-level defects and irregularities.

Radiographic Examination is a versatile NDT method with cost variations depending on joint transportability. Factors like joint thickness, film type, and isotope used influence execution times. This technique requires specialized equipment and proper film preservation.

Ultrasonic Examination in standard form has an estimated execution time of 2 meters per hour. Its exceptional sensitivity makes it ideal for detecting internal defects. However, complex geometries may extend inspection times, and post-processing is often required.

Advanced Ultrasonic Examination methods (such as "UTPA" and "TOFD") maintain a similar execution time of around 2 meters per hour. These methods offer improved efficiency due to user-friendly outputs. However, they demand skilled operators and come with higher initial equipment costs.

Regardless of the chosen NDT method, the training and qualification of personnel are paramount. Skilled and certified operators are crucial for accurate assessments and reliable results.

In summary, understanding the intricacies of welding techniques, associated costs, and non-destructive testing methods is essential for optimizing production processes and ensuring the delivery of high-quality welded products. Proper assessment and implementation of these factors contribute to both economic viability and product integrity in the welding industry.

