Please fill in the name of the event you are preparing this manuscript for.	Event Name
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Please fill in your manuscript title.	Non-Destructive Testing Techniques for Offshore Underwater Decommissioning Projects through Cutting Detection: A State of Review

Please fill in your author name(s) and company affiliation.

Given Name	Surname	Company
Noor Amila Wan Abdullah	Zawawi	Universiti Teknologi PETRONAS
M.S.	Liew	Universiti Teknologi PETRONAS
Wesam Salah	Alaloul	Universiti Teknologi PETRONAS
E.	Lim	Universiti Teknologi PETRONAS
Muhammad	Imran	Universiti Teknologi PETRONAS
Iraj	Toloue	Universiti Teknologi PETRONAS

Abstract

In Malaysia, most of the offshore structure beyond their design lifetime over 25-30 years. With over 30 years of extensive offshore oil and gas development, Malaysian sea has inherited many ageing offshore platforms that have reached the decommissioning timeline. Underwater decommissioning is a challenging and expensive job especially when a company is not getting any benefit. The efficient, economical and environmentally friendly technique is highly desirable. The main objective of this paper is to discuss the available techniques for the nondestructive test (NDT) that can be potentially used for the decommissioning project to identify clear cut during cutting. Therefore, this paper discusses the stat of the art techniques that can be used preferably underwater NDT for cut detection application. The approach will focus on existing methods available for NDT. There are various NDTs but the current study only focused on the techniques that can be used underwater monitoring. Therefore, review of past studies and techniques that are commonly used in industry for NDTs will be discussed, particularly for Alternative Current Field Measurement (ACFM), Magnetic Partial (MPI), Eddy-Current (EC), Ultrasonic testing (UT), Radiographic Testing (RT), Visual Testing (VT) and Acoustic Emission (AE) Testing techniques will be discussed with real application in O&G with selected case studies. In the end, the advantages and disadvantages will be discussed to compare the suitability for the decommissioning project. The matrix presented summarized the key elements that need to consider before selecting a system for decommissioning project for considering cut detection

1. Introduction

For any underwater cutting technique to be effective, it must be safe, reliable, repeatable, flexible and adaptable under field conditions, environmentally sensitive, and economical. The successful (total or partial) removal of steel jackets and concrete support structures is largely dependent on effective and reliable subsea cutting techniques, extensive subsea cutting research and development programs have been launched in the last 20 years to extend the capabilities of subsea cutting techniques. Cutting and serving techniques are grouped into two general categories namely explosive and non-explosive. Explosive cutters refer to bulk charges, configured bulk charges, and other cutter charges (Thornton & Wiseman, 2000). While no-explosive cutters refer to mechanical cutters such as abrasive water jet (AWJ) cutters. Jacket, piles and conductors are being severed by either one of the described subsea cutting tools, in which some of which provide proof that the cut is 100% complete namely diamond wire and hydraulic shearing. However, the cutting performance AWJ the most commonly used techniques are still ambiguous and difficult to verify. According to (Thornton & Wiseman, 2000) explosive severs about 66% of piles and bracing members, while non-explosive cuts around 34%, where two-thirds of non-explosive cutters are made with AWJ. AWJ cutters have the likelihood to be used more than other conventional subsea cutter because they are efficient, safe and cost-effective (DeMarsh, 2000; Offshore, 2010). Notwithstanding AWJ cutting technology is cost-effective, they may leave material uncut at the starting point of the abrasive and when the alignment of the cuter jetting and the target are sub-optimal. Meaning to say, abrasive water jet cutting of thick walls is not yet fully dependable and require a method to be adapted for verification purpose.

2. Non-Destructive Testing (NDT)

The field of NDT is a very broad, interdisciplinary field that plays a critical role in inspecting that structural component and systems perform their function in a reliable fashion. In certain applications, the evaluation of structures without destructing their engineering properties is very important to ensure smooth delivery of the job. This kind of assessment is carried out with NDT methods allowing a proper inspection of materials and structures without destroying their original texture and integrity. Traditional NDT is utilized to determine the integrity of various piping systems and piles within the operational structures. The non-destructive approach is commonly used to monitor the overall dynamics and the condition of a system while in operation (Devriendt et al., 2010). This study is focused on the investigation the suitability of cut detection NDT which is likely to lead to desired subsequent outcomes through NDT selected methods based on weighting criteria such as cutting reliability and degree of accuracy.

3. Techniques Available

Underwater, where a large number of species from very different taxa interact acoustically (e.g. cetaceans, pinnipeds, teleosts and crustaceans); the potential for disturbance from decommissioning operation is high. Sound is used for communication finding prey, echolocation locating recruitment sites in fish finding potential mates and avoiding predators (Lugli et al., 2003). Decommission activities significant sources of noise could cause damage to the acoustic systems of species within 100 m of the source and are expected to cause mobile organisms to avoid the area. Any effects of the noise will depend on the sensitivity of the species present and their ability to habituate to the noise and will reduce when the level of noise has decreased after completion of the construction or decommissioning phase

(Gill, 2005).

Comparing the different technologies is extensive and not clearly limited. Therefore, the scope of this paper is limited to choose the best cutting detection technology that can work together with any cutting technology to monitor the performance of cutting. The goal of this study is to choose a technology that is not only economical, environment-friendly but also technically strong and reliable.

4. Methods commonly used for underwater Non-Destructive Test

There are several NDT, but the current study only focused on NDT which are most commonly used for underwater Non-Destructive Tests:

1. ACFM - Alternating Current Field Measurement Testing
2. MPI - Magnetic Particle Testing
3. ECT - Eddy-Current Testing
4. UT - Ultrasonic Testing
5. RT - Radiographic Testing
6. VT - Visual Testing
7. AET- Acoustic Emission Test

4.1. ACFM- Alternating current field measurement NDT

Alternating current field measurement (ACFM) is an electromagnetic inspection technique that introduces an alternating current into the surface of a component to detect surface-breaking cracks (Arabia, 2019; Li et al., 2016). The presence of cracks disturbs the electromagnetic field and the return signal is instantaneously converted by advanced mathematical techniques so that operators are alerted to the presence of defects. Immediate defect sizing and recording is a major benefit compared to other NDT methods. Results from independent testing show ACFM match magnetic particle inspection (MPI) performances when inspecting underwater structural welds. The amount of missed and spurious signals is significantly lower with ACFM compared to MPI and conventional eddy current testing (ECT) (Customers, 2019).

The technique is routinely used by oil and gas industries for structural weld inspection. Since then it has been successfully applied to the onshore process plant. Other applications include in-service crack detection in vessels. Although developed ACFM Inspection Systems initially for the routine inspection of structural welds, the technology has been improved further to cover broader applications across a range of industries. Few examples of ACFM applied to underwater structures were reported (Francisco Carlos R. Marques et al., 2006; Rizzo, 2013). The formers described the use of ACFM at PETROBRAS, the Brazilian State Oil Company, for the routine structural inspection of offshore platforms (Rizzo, 2013).

The ACFM probe induces a uniform alternating current in the area under test and detects the magnetic field of the resulting current near the surface (Customers, 2019). This current is undisturbed if the area is defect free. A crack redirects the current around the ends and faces of the crack. The ACFM instrument measures these disturbances in the field and uses mathematical modelling to estimate crack size (Customers, 2019; Li et al., 2016; Rizzo, 2013). The lateral and vertical components of the magnetic field are analyzed; disturbances indicate a crack is present, and the size and depth of the crack can be calculated.

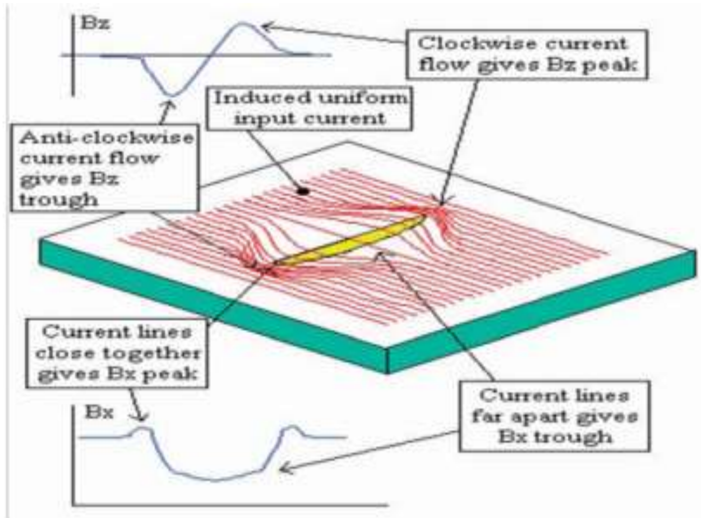

Figure 1. ACFM Principal for Non-Destructive Test (Arabia, 2019)

4.1.1. Advantages

• Fast and immediate results.
• With ACFM's lower cleaning requirements and fewer false calls, inspections are significantly shorter, saving customers money.
• The amount of missed and spurious signals is significantly lower with ACFM compared to MPI and conventional eddy current testing (ECT).
• The method both detects cracks and estimates their size and length. It can inspect any electrically conductive material. Data is recorded electronically for off-line evaluation if necessary and provides a permanent record of indications. Tests can be repeated and compared over time for ongoing monitoring.
• The method is non-invasive and can carry out the inspection without removing any protective paint coating. With suitable probes, the method can be used on hot surfaces.

4.1.2. Disadvantages

• Not recommended for short sections or small items.
• Locations of weld repairs and localized grinding can cause spurious indications.
• Multiple defects reduce the ability to estimate defect depth.
• Equipment bulkier than for MPIT and indications may be more difficult to interpret.
• The probability of detection and false detection rate is generally good, but it is application dependent.

4.2. MPI-Magnetic Particle Testing

Magnetic particle testing was being executed earlier than radiographic testing. Englishman S.M. Saxby in 1868 and American William Hoke in 1917 tried to detect cracks in gun barrels by magnetic indications. The industrial applications were made by Victor de Forest and Foster Doane later than 1929. In 1934, they formed a company with the name of Magnaflux (Jiles, 1990; Na & Kundu, 2002; szutest, 2019).

Magnetic Particle Testing is a test method to detect defects on the surface or open to the surface. The main principle of this method is; it includes the application of magnetic field externally or applying an electric current through the material which in turn produces magnetic flux in the material. At the same time, visible ferrous particles are sprayed on the test material. Surface or open-surface defects in the material creates distortion in the magnetic flux which causes leakage of the magnetic fields around the defect. The magnetic particles are pulled by the surface field in the area of the defect and indicates the location of the defect (szutest, 2019).

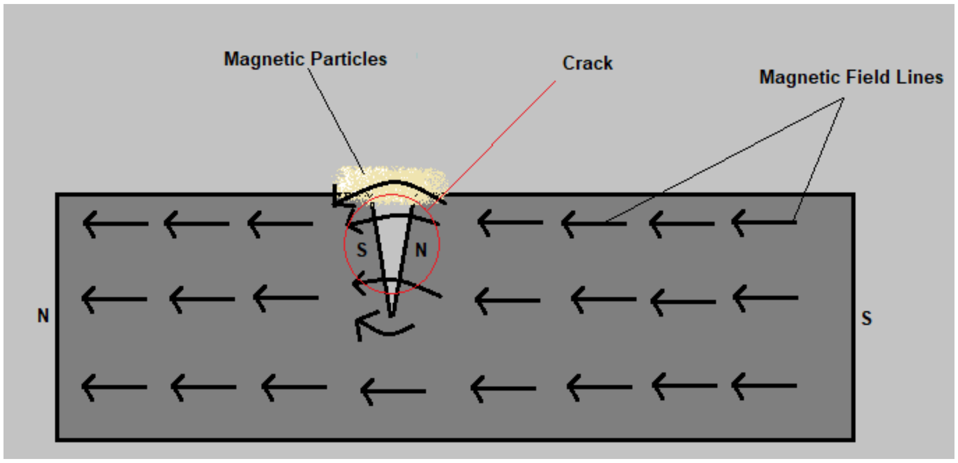

Figure 1. Magnetic Particle Methods Principal for Non-Destructive Test

Magnetic particle inspection (MPI) MPI is used to detect surface and near-surface flaws in ferromagnetic materials, to look for cracking at welded joints and in areas identified as being susceptible to environmental cracking, fatigue cracking, or creep cracking(Rizzo, 2013) which may not be visible to the eye ("Underwater NDT Inspections - FN Diving 24/7 worldwide service," 2019). When the extremities of the crack are located often stop drilling technique is required or other supplementary preventative measures. MPI crack testing can be carried out in the wet or dry ("Underwater NDT Inspections - FN Diving 24/7 worldwide service," 2019).

MPI apart from the visual examination has been the most widely used method underwater. It is a very effective method for detecting surface-breaking cracks, both under and above water. In addition, the examination has to be performed by divers and areas to be examined have to be cleaned. It can only be applied to bare metal specimens, and it is a time-consuming process as surface cleaning is normally required prior to its application (Rizzo, 2013). This method can be applied to ferromagnetic materials only. Any other materials should be tested with different methods (Na & Kundu, 2002).

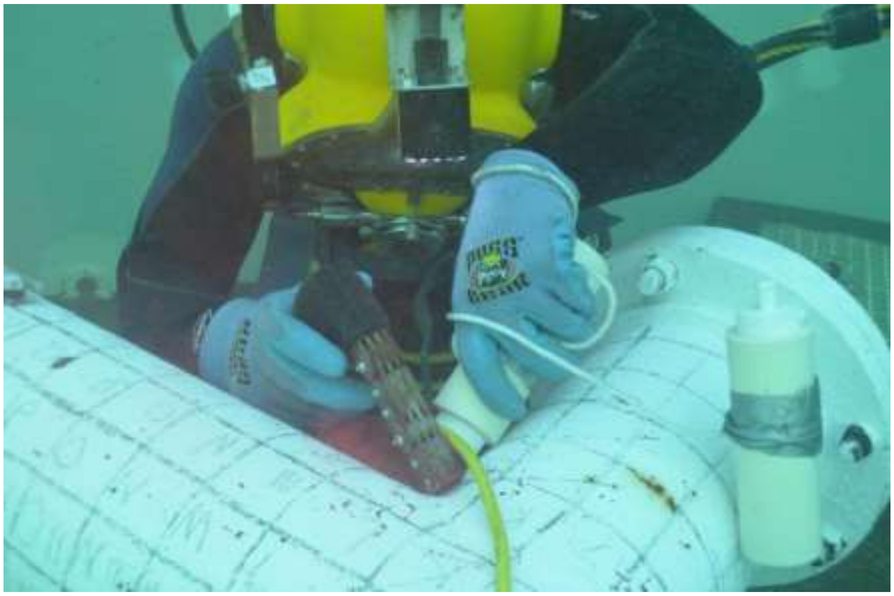

Figure 3. Magnetic Particle Methods testing underwater (CoreIRM, 2019)

4.2.1. Advantages

• Fast and immediate results.
• Doesn’t require a detailed cleaning and can be applied on coated materials. (Up to 50µm)
• Inexpensive.
• Can detect surface and open-surface defects.

4.2.2. Disadvantages

• It can be performed only on ferromagnetic materials.
• Needs equipment working with AC or DC current. Can be expensive in certain situations.
• Parts may require demagnetization and cleaning when the inspection ends.
• Requires a constant power source to work.
• Low sensitivity to detect cracks that run parallel to the magnetic field. In this circumstance
• There is little disturbance to the magnetic field and it is unlikely that the crack is detected. To avoid this limitation the inspection surface is magnetized in two perpendicular directions. Alternatively, techniques using swinging or rotating magnetic fields can be used to ensure that all orientations of crack are detectable.
• Residual magnetic fields left after the inspection is terminated may interfere with welding repairs. These can be removed by slowly wiping the surface with an energized AC yoke.
• Deeply embedded flaws cannot be detected.

4.3. Eddy-Current Testing

Michael Faraday has discovered of electromagnetic induction in 1831. Faraday was a chemist in England, in the 1800’s he is credited with the discovery of electromagnetic rotations, the magneto-optical effect, diamagnetism. A scientist named Hughes recorded changes in the properties of a coil when placed in contact with metals of different conductivity and permeability in 1879. However, it was not until the Second World War that these effects were put to practical use for testing materials. In the 1950's and 60s, many works had been done already, especially in the aircraft and nuclear industries.

Eddy-Current testing is a method to identify surface and near-surface defects. When an energy coil is brought close to the surface of a material, the variable magnetic field of the coil creates eddy currents on the material. These currents tend to magnetize against the original magnetic field. The impedance of the coil near the material is impacted by the presence of induction currents induced in the material.

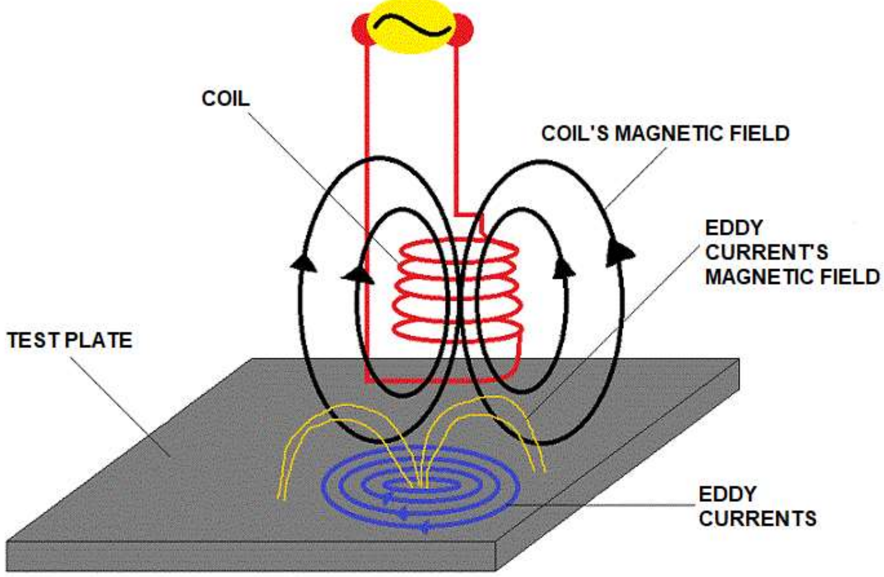

Figure 2. Eddy Current Methods Principal for Non-Destructive Test (Rizzo, 2013)

When the eddy currents in the material change due to defects or material variations, the coil impedance changes. This change is measured and displayed as indicating the defect or material variation. It can be applied to all metallic and alloy materials with electrical conductivity. With eddy current testing, it is also possible to classify materials based on properties such as electrical conductivity or magnetic permeability. In addition, it is also possible to measure coating thickness or thickness of thin metal sheets.

EC based methods measure a material's response to electromagnetic fields over a specific frequency range, typically a few kHz to several MHz (Rizzo, 2013). The principle is illustrated in a magnetic coil with alternating current induces a time-varying magnetic field which causes an electric current to be generated in the test object. These currents produce small magnetic fields around the material that generally oppose the original field and therefore change the impedance of the magnetic coil. By measuring the change in the impedance of the magnetic coil as it traverses the sample, anomalies in the inspected structure can be detected. EC based inspection has the advantages of being non-contact and not requiring surface preparation. However, it can be only used in conductive materials, it is sensitive to lift-off variations, and it is limited to surface or near-surface detection (Rizzo, 2013; Shull, 2016).

Eddy current can be used underwater to quickly determine the presence of a defect without cleaning the hull surface to bare metal. When a crack is detected, the surface is then cleaned to bare metal and underwater magnetic particle is used to define the crack in full-colour contrast to the surrounding metal.

Figure 3. Eddy Current Methods testing underwater

4.3.1. Advantages

- Can detect small defects.
- Fast and highly accurate results.
- Doesn’t require a coupling, able to test without a contact.
- Requires minimum surface preparation.

4.3.2. Disadvantages

- Can only detect surface and near-surface defects and defects parallel to the surface cannot be detected.
- Surface condition is important, otherwise, it will affect the testing.
- Effects such as vibrations and hits will make harder to find defects.
- Works only on conductive materials.
- Experienced people and specialized tools required.

4.4. UT - Ultrasonic Testing

Latest method to come into industrial use. The methods of ultrasound were discovered in 1847 by James Precott Joule and in 1880 by Pierre Curie and his brother Paul Jacques. Not before than 1912, a first application was proposed after the Titanic incident. Englishman Richardson confirmed the identification of icebergs by ultrasound in his patent applications. In France, Chilowski and Langevin started their development to detect submarines by ultrasound during World War I. In 1929, Sergei Y. Sokolo proposed to use ultrasound for testing castings, the same year he created high-frequency vibrations in materials using a quartz crystal. The detection of laminations in plates and fine non-metallic inclusions in hot-rolled profiles became necessary during World War II. Already existing NDT methods such as X-Ray, MT, PT and ET were unable to solve these issues (Center, 2019a).

Industrial use of ultrasonic testing started in three countries: America, England and Germany. Main persons were Adolf Trost, Donald O. Sproule and Floyd Firestone. Sproule and Trost used transmission-technique with separate transmitter and receiver probes. Trost invented the so-called "Trost-Tonge". The 2 probes were contacted on opposite sides of a plate, held in the same axis by a mechanical device – the tonge – and coupled to both surfaces by continuously flowing water. Sproule placed the 2 probes on the same side of the workpiece. So he invented double-crystal probes. He also used this combination with varying distances from each other. Firestone was the first to realize the reflection-technique. Ultrasonic testing is based on transmitting high-frequency sound waves to materials and receiving them back in order to detect any discontinuities. Probes with pulser/receiver speciality are being used to send sound waves. A probe connected to an ultrasonic testing device sends sound waves into the material. The sound waves pass through the material and reflect back to the probe. With a discontinuity found, sound waves will return to the probe before the distance is complete, this will show a discontinuity was present within material.

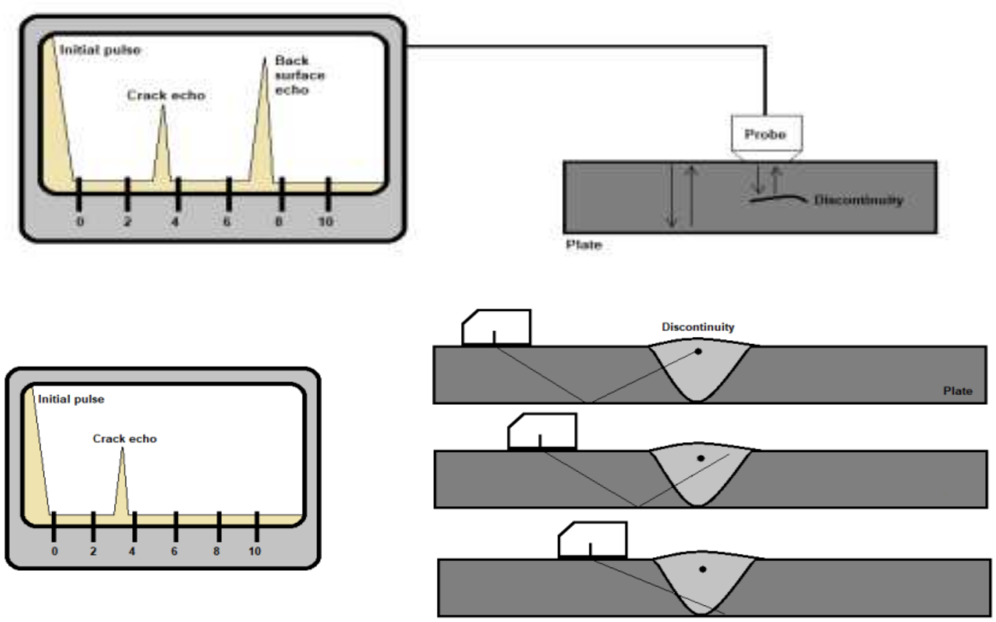

Figure 6. UT - Ultrasonic Testing Principal for Non-Destructive Test

Ultrasonic testing is able to scan any welding seams, castings and forgings. Some of the most common industries that use ultrasonic testing are petrochemical, automotive, aerospace and structural steel, among many others. The ultrasonic Testing system allows for the measurement of Underwater Hull Thickness, Pipe Wall Thickness, Boiler Tube Testing, and Sheet Piling thickness, Heavily Pitted Material, Structural Steel and Offshore Structures.

Figure 7. UT - Ultrasonic Testing under water (Hedayati, 2010)

4.4.1. Advantages

• Fast and highly accurate results.
• It has no harm to the environment or humans.
• Practical and easy to carry equipment.
• Requires minimum preparation.
• Can also be used to measure the thickness.
• Internal discontinuities can be detected.

4.4.2. Disadvantages

• Surface must be accessible.
• Linear defects oriented parallel to the sound wave might not be found.
• Equipment is expensive.
• Materials in different shape, small or thin are difficult to inspect.
• Requires a coupling to transfer the sound wave to test material.
• Experienced people and specialized tools required.

4.5. RT – Radiographic Testing

X-Ray Technique was the first NDT method to come industrial application. Wilhelm Conrad Roentgen discovered X-rays in 1895 during his experiments with cathode rays. He won Nobel Prize in Physics in 1901. In his first publication, he described all effects including possible flaw detection. During that time industry didn’t need this invention yet, but the medicine did. Medical equipment was the first to develop. Only side effect Röntgen could not predict was that X-rays were harmful to human health. Before radiation protection came out, many people lost their life. First technical X-ray applications were done by Richard Seifert around 1930 in Germany. He improved medical equipment, cooperated with welding-institutes. Radiation testing can also be done with radioactive isotopes. This was discovered by Marie Curie, she received Nobel Prize for physics in 1903 (Center, 2019b).

This method of NDT is a technique that uses either x-rays or gamma rays to see the internal structure of a material. High-energy electromagnetic waves penetrate the material. Radiation penetrating the material affects the radiation-sensitive film placed on the other side of the material. When developed, this film reveals the image of the inner part of the material through which the beam passes. The darker areas on the image are evaluated as the indicators of discontinuities. This method can be used to detect internal and surface flaws in all metallic or non-metallic materials. In the industry to produce gamma rays Iridium 192, Selenium 75 and Cobalt 60 are being used, for X–ray x-ray tubes are being used (Center, 2019a, 2019b).

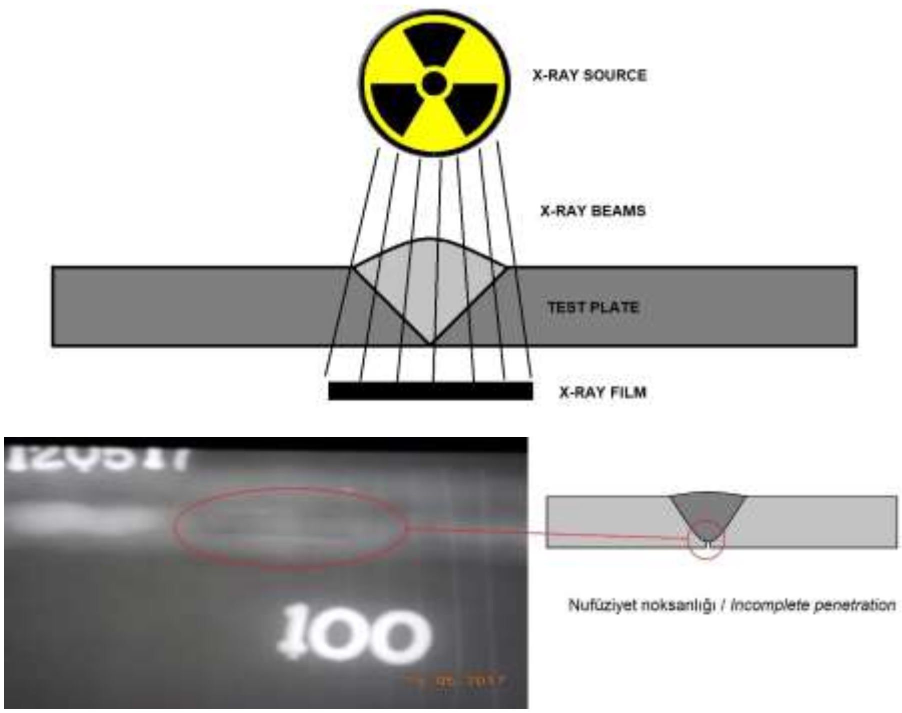

Figure 8. RT – Radiographic Testing Principal for Non-Destructive Test

RT is one of the few NDE methods that can examine the interior of an object and the only NDE method that works on all materials. X-ray based technology has the advantages of being accurate, inherently pictorial, adaptable to examine shapes and sizes, and sensitive to the discontinuity that causes a reasonable reduction of cross-section thickness. However, this method carries the burden of safety hazard concerns. As radiographic methods were proposed to inspect pipes, the use of X-ray technology can be extended to monitor any tubular components and welds underwater (Rizzo, 2013).

4.5.1. Advantages

• Internal and surface discontinuities can be detected.

• Requires minimum surface preparation.
• Test results can be saved for a long time.
• Applicable to many materials.

4.5.2. Disadvantages

• Radiation coming out during the process is harmful to the human body.
• Equipment is expensive.
• Slow process.
• Test material must be accessible from both sides.
• Not possible to determine the depth of the discontinuities.

4.6. VT - Visual Testing

Visual testing is the fastest and cheapest method of Non-destructive testing. It's the first step of every inspection before any other Non-destructive test starts. When performing the visual test with the naked eye, equipment such as magnifying glass, light source, borescope and mirror can also be used. The condition of the surface is important in order to detect discontinuities such as cracks, porosities and undercuts. Required cleanings must be finished before visual testing starts. It can be applied to any metallic or non-metallic materials.

Visual testing may seem like an easy method, but it has it's own inspection terms and the experience of the staff is important. The test must be performed under enough light, minimum 500 lux, with an angle not lower than 30° and the distance between the eye and the surface shouldn't be less than 300 mm (szutest, 2019). For underwater pipeline inspection, visual inspection is very old-fashioned (Na & Kundu, 2002).

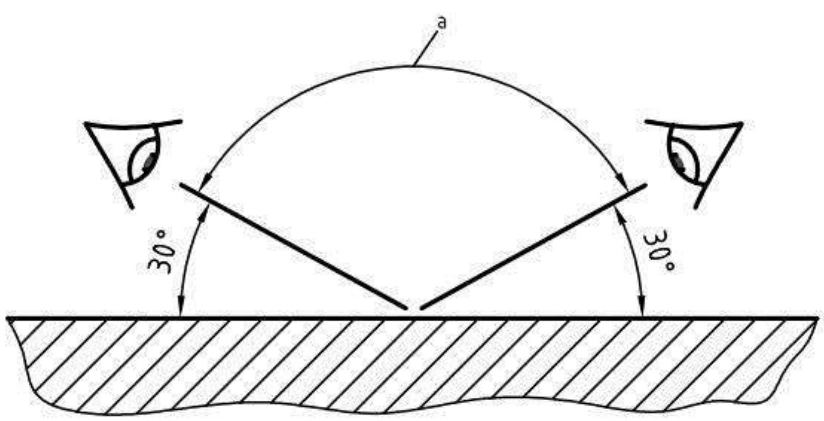

Figure 9. VT-Visual Testing for Non-Destructive Test

4.6.1. Advantages

• Fast and immediate results.
• Requires minimum preparation.

• Inexpensive.
• Cheap equipment.

4.6.2. Disadvantages

• Only surface indications can be detected.

4.7. AET - Acoustic Emission Test

Acoustic emission is the phenomenon of radiation of acoustic waves in solids that occurs when a material undergoes irreversible changes in its internal structure, for example as a result of crack formation or plastic deformation due to ageing, temperature gradients or external mechanical forces. In particular, AE is occurring during the processes of mechanical loading of materials and structures accompanied by structural changes that generate local sources of elastic waves. This results in small surface displacements of a material produced by elastic or stress waves generated when the accumulated elastic energy in a material or on its surface is released rapidly. The waves generated by sources of AE are of practical interest in structural health monitoring (SHM), quality control, system feedback, process monitoring and other fields. In SHM applications, AE is typically used to detect, locate and characterize damage.

Acoustic emission is the transient elastic waves within a material, caused by the rapid release of localized stress energy. An event source is a phenomenon which releases elastic energy into the material, which then propagates as an elastic wave. Acoustic emissions can be detected in frequency ranges under 1 kHz, and have been reported at frequencies up to 100 MHz, but most of the released energy is within the 1 kHz to 1 MHz range. Rapid stress-releasing events generate a spectrum of stress waves starting at 0 Hz, and typically falling off at several MHz.

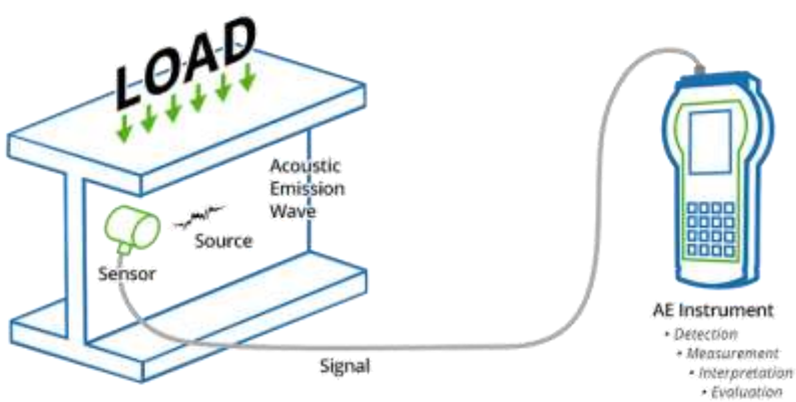

Figure 10. AE Testing for Non-Destructive Test (Acoustic, 2019)

Acoustic Emission (AE) testing is a powerful method for examining the behaviour of materials deforming under stress. The Acoustic Emission NDT technique is based on the detection and conversion of high-frequency elastic waves into electrical signals. This is accomplished by directly coupling piezoelectric transducers on the surface of the structure under test and loading the structure. Sensors are coupled to the structure, and the output of each sensor (during structure loading) is amplified through a low-noise preamplifier, filtered to remove any extraneous noise and further processed by suitable electronic equipment.

Small-scale damage is detectable long before failure, so AE can be used as a non-destructive technique to find defects during structural proof tests and plant operation. AE also offers unique capabilities for materials research and development in the laboratory. Finally, AE equipment is adaptable to many forms of production testing, including weld monitoring and leak detection.

The three major applications of AE techniques are: 1) source location – determine the locations where an event source occurred; 2) material mechanical performance – evaluate and characterize materials/structures; and 3) health monitoring – monitor the safe operation of a structure, for example, bridges, pressure containers, and pipelines, etc. More recent research has focused on using AE to not only locate but also to characterizes the source mechanisms such as crack growth, friction, delamination, matrix cracking, etc. This would give AE the ability to tell the end-user what source mechanism is present and allow them to determine whether structural repairs are necessary.

The technique is used, for example, to study the formation of cracks during the welding process, as opposed to locating them after the weld has been formed with the more familiar ultrasonic testing technique. In a material under active stress, such as some components of an aeroplane during flight, transducers mounted in an area can detect the formation of a crack at the moment it begins propagating. A group of transducers can be used to record signals, then locate the precise area of their origin by measuring the time for the sound to reach different transducers. The technique is also valuable for detecting cracks forming in pressure vessels and pipelines transporting liquids under high pressures. Also, this technique is used for the estimation of corrosion in reinforced concrete structures.

4.7.1 Advantages

- High sensitivity, early and fast detection of discontinuities (Walsh et al., 2015).
- Able to scan a structure in one phase, tests don’t take long.
- Having access to sensors is enough, instead of the whole surface.
- Doesn’t depend on the size of the defect. (MT, UT, RT does)
- Real-time monitoring, results can be received during the test.
- Allows locating discontinuities on big structures. (e.g. LPG tanks or storage tanks)
- AE is used for a wide range of applications including leak detection, particle impacts, electrical discharges and a variety of friction-type processes etc.
- Other areas of interest include higher-frequency machinery health monitoring and predictive diagnosis.
- Acoustic emission is a unique non-destructive test method that allows Overall examination of large structures during operation, detection of flaws at their early stages, flaw typification and assessment.
- Study of dynamic material behaviour, developing fracture and material properties.
- Control over manufacturing processes and production, machinery health monitoring.

4.7.2 Disadvantages

- The signals containing frequencies higher than half the Nyquist frequency is that these higher frequency components are aliased, or folded back, into the lower frequency range. In the worst cases, this can result in gross distortions of the original signal. If a lower sampling frequency is used, the low pass filters in the system should be set for considerably less than the Nyquist frequency.

• AE is the lack of traceability of the measurements to fundamental units. This means that results cannot be transferred even between like structures to compare performance.

5. Conclusion

Underwater structures play a vital role in modern society. Navies must ensure the security of their assets including the large underwater ship hulls. Oil and natural gas companies need to secure the operation of their offshore infrastructures. To this end, human divers conduct a thorough inspection of structures below the waterline. This inspection is subjected to the athletic and technical skills of the operators. Moreover, the structures might be too large to be completely checked by hand in a timely manner. If the simple inspection is conducted, little to no visibility due to turbid water requires close proximity to the structure which might endanger the diver or simply becomes impractical. Owing to the environmental conditions under which some of the underwater structures operate, it is important to guarantee proper maintenance and avoid any failure that can compromise the marine environment and lead to economic losses. In this paper, we briefly reviewed the most common method used for the nondestructive evaluation and structural health monitoring of underwater structures. The review included methods based on electromagnetic and stress waves, visual inspection, and radiography. Advantaged and drawbacks of each methodology as it applies to underwater systems were reported. In this report, we briefly reviewed the most common method used for the nondestructive evaluation and structural health monitoring of underwater structures. The review included methods based on ACFM, MPI, Eddy Current, UT, VT and AE. Advantaged and disadvantages of each methodology as it applies to underwater systems were reported. A comparison matrix is developed to compare and rate the NDT for underground water inspection as shown in Table 1.

The matrix presented summarized the key elements that need to consider before selecting a system for decommissioning project for considering cut detection. Based on advantages & disadvantages and comparison matrix AE and secondly ACFM method found most suitable compared to other methods for underground water inspection due to following key reasons, ACFM required equipment which is bulkier than for MPI and indications may be more difficult to interpret. Secondly, the probability of detection and false detection rate is generally good, but it is application dependent, MPI most widely used method for underwater NDTs. However, the examination must be performed by divers or ROVs and areas to be examined have to be cleaned, Eddy Current can only detect surface and near-surface defects and defects parallel to surface cannot be detected. Surface condition is important, otherwise, it will affect the testing. Effects such as vibrations and hits will make harder to find defects. Works only on conductive materials, UT the surface must be accessible and requires coupling to transfer the sound wave to test material. The linear defects oriented parallel to the sound wave might not be found. This method is required for expensive equipment. Materials in different shape, small or thin are difficult to inspect, VT: cannot detect the depth of cut and difficult verify they cut. In this technique, the examination must be performed by divers or ROV, therefore, the technique is not suitable.

Table 1. NDT Comparison Matrix

SNO	Type of Technology	1	2	3	4	5	6	7	8	9	10	11	Total Score
1	**Alternating Current Field Measurement (ACFM)**	o	~	o	o	o	~	o	o	o	~	o	**9.5/11**
2	**Magnetic particle Inspection (MPI)**	o	o	-	x	o	~	x	x	x	x	x	**3.5/11**
3	**Eddy-Current Testing (ECT)**	o	o	o	o	-	~	o	o	x	~	~	**7.5/11**
4	**Ultrasonic (UT)**	o	o	o	o	o	~	o	x	o	o	-	**9/11**
5	**Radiography (CR) (X-ray)**	o	o	o	o	o	~	o	o	~	o	-	**9/11**
6	**Visual Inspection (VI)**	o	o	o	x	o	x	x	o	o	x	-	**7/11**
7	**Acoustic emission (AE)**	o	o	o	o	o	o	o	o	o	~	o	**10.5/11**

o Yes, **X** No, **~** Limited use or required special arrangements, **-** No information

1. **Work in under water:** Capable to work under sea water
2. **Portable:** Easy to handle and setup / transport
3. **Easy to work/Fast:** Real time monitoring /instant data visualization
4. **Accurate:** Accurate fault detection (cut no cut detection)
5. **Environment friendly:** Less impact to environment and sea species
6. **Through-coating detection:** Detect fault under the coating (cut under the coating)
7. **Real Time Monitoring**: Results can be found online/instantly
8. **No need for chemicals:** No need to apply any chemical to record fault on surface
9. **No Material Dependency:** deduct fault on any surface steel/stainless-steel etc.
10. **Size crack length and depth:** Full Details of fault /crack depth, length record
11. **High PoD and low false call rate:** (**P**robability **o**f **d**etecting crack) Usually as a function on flaw size. Sometimes as a function of other parameters as well. NDTs value is maximized when POD is high; it is not the smallest crack can find, it is the largest crack that you might miss, that defines your NDT capability.

Acoustic emission technology is used for detection of leaks, cracks of different nature and corrosion damage in underground petroleum piping. A special study conducted in Europe over 150 tanks of Shell, Dow, Exxon, ICI, DSM, Q8, Total companies that were inspected internally after AE examination has shown a very good correlation between the severity of AE findings and extend of the following repairs.

Despite AE as a suitable NDT for underwater testing, there is still some gap that is not covered in the previous literature survey. Currently, the application of the AE method in three-dimension is not explicitly mentioned in the existing literature survey. There are some studies that visualize the cracks in 3D using only 2 sensors but this technique required a lot of equipment and polish on the surface with an additional digital microscope (x-ray) which is difficult for decommissioning projects. Secondly, the exact distance, number of sensors, type of sensors and range required to detect the cut for the circular column is still arguable.

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