Future Maintenance Management in Renewable Energies

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Abstract This chapter describes the future on maintenance management in renewable energy industry. The main advances and research studies shows that it will be based on non-destructive testing (NDT). NDT are tests performed to detect internal or surface discontinuities in materials or determine certain properties. NDT leads to improvement of product quality, public safety and prevention of catastrophic failures. NDT techniques are used in Structural Health Monitoring (SHM) systems for Fault Detection and Diagnosis (FDD). Some NDT techniques are used to prevent serious failures in critical components such as blades, gearbox, tower or receiver tubes. NDT is increasing in many scientific and industrial fields, from wind energy production to the transportation of gases and liquids. Consequently, it is possible to reduce the corrective/preventive maintenance tasks, and to increase the life cycle of the structure.

1 Introduction

Non-Destructive Testing (NDT) is used in Structural Health Monitoring (SHM) systems for Fault Detection and Diagnosis (FDD) [1]. Within the context of Condition Based Maintenance (CBM), some NDT techniques are used to prevent serious failures in critical components such as blades, gearbox, tower or receiver tubes [2, 3].

NDT has become an essential technique for the development of SHM systems. NDT uses are increasing in many scientific and industrial fields, from wind energy production to transport. The NDT progress depends on the continuous changes of the industry to suit current scenarios. The benefits that these new techniques provide are related to the improvement of the product quality, public safety and

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especially the prevention of faults. The main consequence is the reduction of costs, since they can anticipate potential failures that could involve both material and human losses to reduce the corrective/preventive maintenance tasks, and to increase the life cycle of the structure. Other advantages that they present are related to the forecasting analysis based on the data acquired in a real-time mode, as well as the establishment of FDD techniques [4, 5].

NDT are tests performed to detect materials for internal or surface discontinuities, or to determine properties of the same. It is also applied to view the properties of welds, parts and components or to determine the thickness of a material. The indications must be performed by qualified operators.

Compared with destructive testing, it provides less accurate data about the object under study but are usually less expensive because the part is not destroyed. The damage suffered by the piece is zero or almost zero and does not alter its physical, chemical, or mechanical dimensional properties.

Application Areas:

- *Quality control*: This includes the tests performed to detect discontinuities, impurities and defects, characterization of materials and dimensional metrology.
- *Maintenance of facilities and equipment*: The purpose of these is to evaluate corrosion and deterioration caused by environmental agents, determining stresses, leak detection, etc.
- *Preservation and study of cultural heritage*: These tests look for defects and information about the structural state of historical monuments.

2 Classification

Penetrating Liquids

Liquid Penetrant Inspection (LPI) or Dye Penetrant Inspection (DPI) has wide applicability. It is used to detect flaws or surface discontinuities on nonporous materials such as metals, glasses, ceramics, etc. It was introduced in the industry looking for an alternative method of magnetic particles, which requires materials with ferromagnetic characteristics [6] (Fig. 1).

Magnetic Particle Inspection (MPI) is acting on the principle of the capillary effect (i.e. the ability of certain liquids to penetrate and be retained in the surface discontinuities). It depends on three properties: Wettability, surface tension and viscosity.

Magnetic Particle Inspection

It is used to detect cracks, surface or subsurface discontinuities in ferromagnetic materials. It is based on the physical principle of magnetism (attractiveness between metals).

This method involves to inspect the magnetized piece, then magnetic particles are applied subsequently and the results are studied according to the grouping of particles [7]. Finally, the piece is demagnetized and cleaned.

Fig. 1 Inspection employing penetrating liquid

Eddy Current or Foucault

It is based on the principle of electromagnetic driving. For that purpose, a AC generator is used. The generator is connected to a test coil that produces a magnetic field [8]. If the coil is placed near a material which is electrically conductive, the field of the coil will induce an electric current in the material to be inspected. This current will produce a new magnetic field, which is called secondary field and will be proportional to the first field but opposite sign. As the induced current is alternating, whenever the current becomes zero, the secondary magnetic field will induce a new electric current in the coil. This occurs when the current changes phase.

Industrial Radiography

A body exposed to X- or Gamma rays absorbs energy in proportion to its thickness, density or configuration [9]. This method involves bombarding an object with a beam of X or Gamma rays. Part of the radiation is absorbed by the object itself and the unabsorbed part is recorded by a printing plate. This is revealed displaying an image and it can be observed changes in tonality which are associated with changes in the material, like defects.

Thermography

When a material contains imperfections, they alter the rate of heat flow there around due to high temperature gradients and hot spots are formed. In this technique a coating which acts temperature is applied to the material surface [9]. After the material is heated uniformly and then allowed to cool. The temperature around imperfections is higher than in other areas, so with the help of coating can be detected those points with different colour.

Among other applications with thermography they are: to detect faulty joints or delamination of layers that are part of composite materials.

Acoustic Emission

Acoustic Emission (AE) is a passive but dynamic Non-Destructive Evaluation (NDE) technique which is extensively used for SHM by the industry. The principle of AE is based on the detection of transient elastic waves emitted when the component under evaluation is loaded up to a sufficient level to cause damage growth. AE signals are high frequency events with very small magnitude. In order to detect AE signals very sensitive piezoelectric sensors are employed. The piezoelectric crystals convert the resulting displacement in the surface of the component to electric signals which are then suitably amplified using appropriate amplification.

AE signals can be generated from various sources including dislocation movement, plastic deformation, crack growth, corrosion, erosion, impact, friction and even phase transformation. In composite materials signals can arise from fibre deboning, delamination, matrix cracking and fibre failures. Depending on the type of damage evolution mechanism different wave types may appear [10]. Crack growth in a metal will usually give rise to a burst type waveform. By analysing the different waveforms and other features of the AE signal it is possible to recognise the feature in the material that is giving rise to specific aspects of the recorded AE activity (Fig. 2).

It is a method used to detect elastic waves occurring spontaneously. When a material is subjected to repetitive strain it is produced micro-cracks in the material releasing energy that is directed to the outside of the piece. This energy is released as elastic wave that produces sound. Through sensors disposed on the surface it is possible to capture and record the sound. These sensors convert the mechanical energy of that sound into small electrical pulses that are often accompanied by amplifiers to record and analyse the signal more clearly.

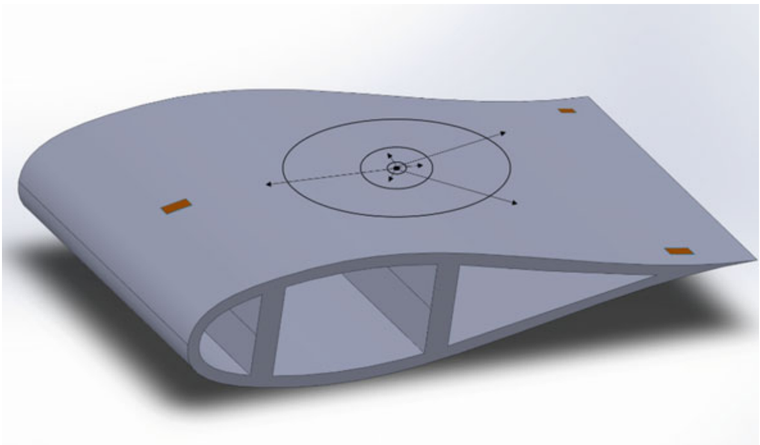

Fig. 2 Mechanical and elastic waves propagation from the acoustic emission source

Ultrasonic Inspection

Ultrasonic inspection is a non-destructive method where a set of mechanical high frequency waves (above 20 kHz) are applied to the material to be examined. These waves travel through the material, being reflected when it reaches the interface or a discontinuity. This beam is then analysed paying attention to three points:

- The Wave reflection on the interfaces
- The Transit time (Time of flight or ToF) of the ultrasound wave.
- The Attenuation of sound waves in the workpiece due to absorption and scattering within the workpiece.

Thus the presence, size and location of discontinuities is determined.

Ultrasonic Inspection Phased Arrays

Ultrasonic phased arrays consisting of several elements can increase the speed and accuracy of the inspection as well as remove some of the limitations related with the accessibility to the surface of the component since the interrogating beam can be scanned and steered in the direction of interest without having to move the probe itself. Furthermore, ultrasonic phased arrays can produce detailed C-scan images providing a useful visual record of the inspection. Two-dimensional images can be used to reconstruct three-dimensional images of the inspected component (Fig. 3).

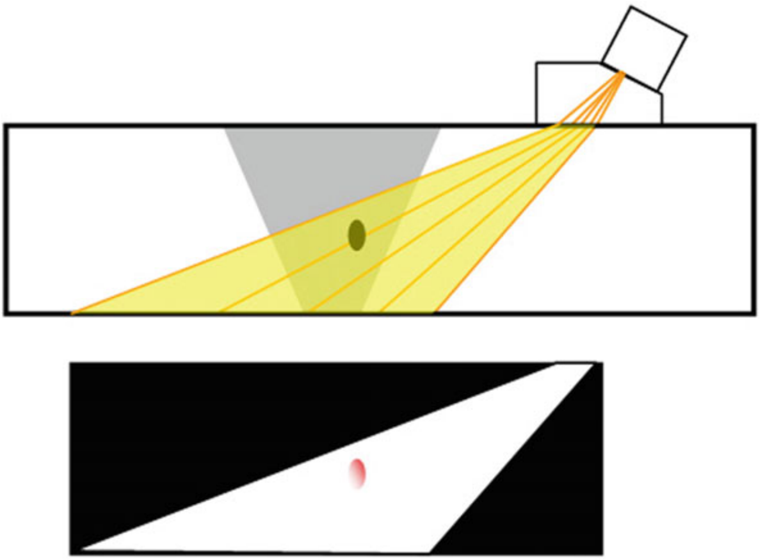

Fig. 3 Checking phased array probe resolution

3 Guided Waves

Inspection techniques using guides waves have gained popularity among structural monitoring techniques. This is due in large part to the drawbacks encountered in other NDT techniques, such as thermography and radiography. An example of one such drawback occurs when examining solar concentrator pipes. Thermography has a limited ability to identify internal defects if they are not outwardly manifested as temperature, and industrial radiography is dangerous for people who are close to the inspection site. Furthermore, the long range of the guided waves can inspect a greater distance than other techniques (Fig. 4).

The inspection by guided waves consists of the excitation of an ultrasonic transducer, which generates ultrasonic waves that are propagated through the pipe [11]. The main advantage offered by this technique, compared with traditional ultrasonic methods, is the ability to inspect structures, such as plates or pipes, along several meters. This technique permits us to know the state of the pipe at a particular location. In some cases, hundreds of meters can be inspected without the relocation of the transducer.

Novel methodologies in signal processing are being published [12], such as predictive analysis online, in order to be employed in structural health monitoring and ultrasonic waves. This waves can be generated in structures like plates or pipes.

3.1 *Structures with Two Surfaces Like Plates*

In these structures Lamb waves and Shear Horizontal (SH) waves are generated. Lamb waves are guided waves propagating in plate or shell type structures. His interest has been growing for its ability to detect damage to these structures (Fig. 5).

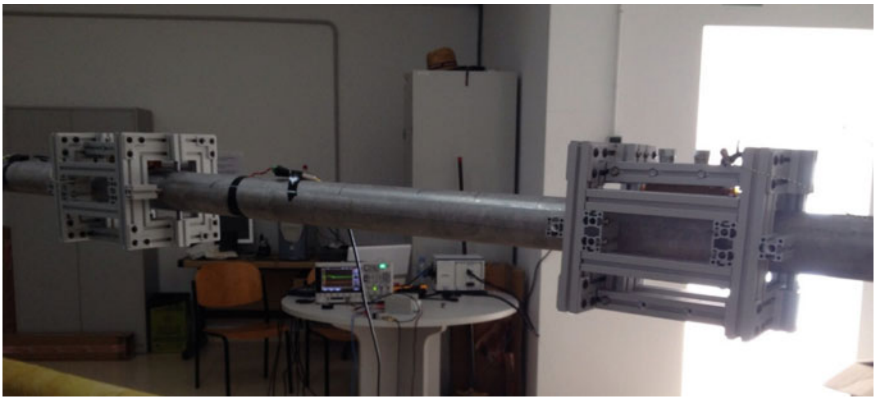

Fig. 4 Inspection of pipes by long rage ultrasonic

Fig. 5 Inspection of delamination in a wind turbine blade employing ultrasonic guided waves

In Lamb waves, energy is confined between the two surfaces and its attenuation is lower [13]. Lamb waves are composed of two different vibration modes, the symmetric and anti-symmetric modes (S0 and A0).

The SH waves have a direction of propagation perpendicular to the particle movement direction. As Lamb waves, SH waves also have the symmetric modes or antisymmetric (SH0, SH1…). These waves are used to inspect plates are embedded, because hardly affected by external forces.

3.2 Pipe Type Structure

Cylindrical Lamb Waves

Lamb waves are guided waves that propagate in thin plate structures or shell structures. The interest in using Lamb waves to identify structural damage has increased in recent years. Damage identification using Lamb waves is in an early stage of development compared with other techniques such as ultrasonic scanning [14–16]. Lamb waves can also be generated in tubular structures such as in a pipe where thickness is much smaller compared to diameter. The propagation of Lamb waves in pipes is similar to those in thin plates with the addition of some peculiarities. Cylindrical Lamb wave's modes are longitudinal, torsional and flexural, labelled with *L*, *T* and *F* respectively. The cylindrical Lamb modes have two integers, $L(n, m)$, $T(n, m)$, and $F(n, m)$, ($n, m = 0, 1\ldots$). Specifically, $n = 0$ indicates that the pipe is axially symmetric which is the case in most applications. The integer *m* indicates the mode number, in particular, $L(0, 1)$ propagates through the thickness of the pipe similar to the A_0 mode in flat plates, and $L(0, 2)$ mode propagates

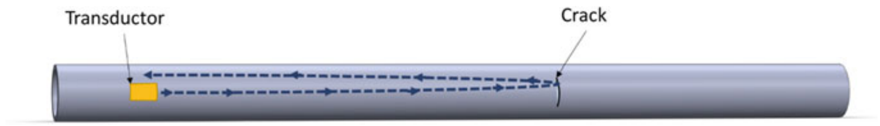

Fig. 6 Inspection of pipes employing guided waves

similar to the S_0 mode in plates. $L(0, 1)$ and $L(0, 2)$ are the most appropriate modes for damage identification because their axisymmetric properties facilitate the inspection along the circumference of the pipe.

- Longitudinal waves: This mode is very similar to the symmetric and antisymmetric modes which appear in plates
- Flexural waves: These modes are not symmetrical about the axis (Fig. 6).
- Torsional waves: They are similar to the Shear Horizontal waves and are primarily used to inspect buried or embedded pipes, due to they suffer less attenuation. This mode has axial symmetry and the particles only have circumferential displacement.

4 Theoretical Principles of the Infrared Thermography

Infrared thermography is the technology that, using the physical principles described above, considers the use of optical-electronic devices to detect and measure the radiance emitted by a specific object or surface.

The beginning of the thermography can be attributed to the German astronomer Sir William Herschel, who conducted experiments with sunlight in 1800 [17]. Herschel discovered infrared radiation by passing sunlight through a prism and measuring the temperature in different colours obtained with sensitive mercury thermometer. Twenty years later, the German physical Thomas Seebeck discovered the thermoelectric effect [18], given the origin of the "thermomultiplier". Macedonio Melloni improved the thermomultiplier, creating the thermopile, a set of thermomultipliers in series, and concentrating the thermal radiation for detecting the body heat from a distance of 9 m [19]. The thermography was used for non-military applications in the sixties in a variety of industrial applications [20, 21], e.g. in the inspection of large electrical transmission and distribution systems, but the equipment employed were big, slow to data acquisition and with low resolution. Continuing advances in military applications in the seventies led to the first portable systems that could be used in industrial applications such as building diagnostics [22] and NDT of materials [23].

Remote sensing techniques are based on the reception and analysis of the electromagnetic energy reflected or emitted by a surface (Fig. 7). Data collected by

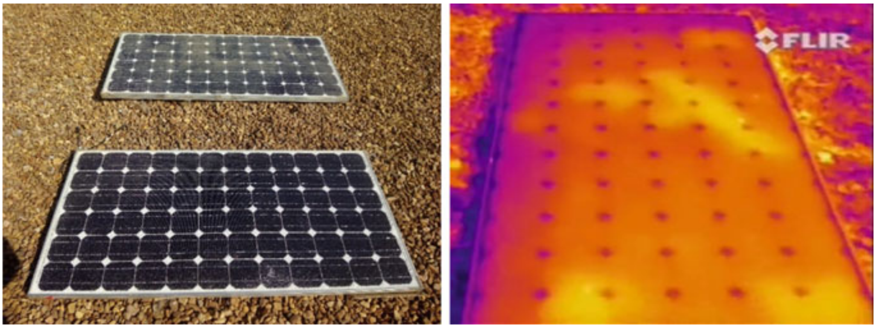

Fig. 7 Infrared thermal inspection of solar panels

remote sensors can be used to retrieve features and parameters of the observed surface, without physical contact [24].

In the thermal infrared, the emitted energy is related to the kinetic temperature of the radiating body though the well-known Planck's law (first assuming a perfect radiator or black body):

$$B_\lambda(T) = \frac{C_1}{\lambda^5\left(e^{C_2/\lambda T} - 1\right)} \tag{1}$$

where B is the spectral radiance (W m^{-2} μm^{-1}), at wavelength λ (μm), C_1 and C_2 are physical constants ($C_1 = 3.74 \times 10^8$, $C_2 = 1.439 \times 10^4$), and T (K) represents the physical temperature of the object. Thermal infrared is the region of the electromagnetic spectrum ranging between 3.0 and 100 μm. However, the spectral window 8-14 μm is traditionally used in remote sensing applications due to the low absorption of the water vapour and the neglected contribution of reflected sunlight in this range.

In practice, real objects are not ideal blackbodies and the radiance of a body at kinetic temperature T is reduced by the emissivity (ε_λ) factor according to:

$$L_\lambda(T) = \varepsilon_\lambda B_\lambda(T) \tag{2}$$

where L is the emitted radiance. Emissivity depends on the substance and varies with wavelength, so that every single surface or body is characterized by its spectral signature.

This emissivity has an effect on the environmental radiance reflected by the surface and also measured by the remote sensor. According to the radiative transfer equation:

$$L_\lambda(T_R) = \varepsilon_\lambda B_\lambda(T) + (1 - \varepsilon_\lambda)L_\lambda^\downarrow \tag{3}$$

where T_R is the radiometric temperature corresponding the real temperature T, and $L^{\downarrow}$ is the down welling environmental radiance.

5 Conclusions

Wind and solar energy powers have become the most important renewable energies worldwide in recent years. The reduction in operating and maintenance costs of the turbines has been identified as one of the biggest challenges to establish this energy as an alternative to fossil fuels. Predictive maintenance can detect a potential failure at an early stage reducing operating costs, especially in areas of difficult access.

Non-destructive tests have emerged as an effective method to detect defects and failures in those crucial pieces for the proper functioning of the plant. Guided ultrasonic waves offer possibilities as NDT to inspect structures for large cracks and corrosion.

Infrared thermography presents a simple and effective way to increase productivity in solar plants by detecting the broken cells [25]. This helps to generate a more optimal maintenance strategy, reducing costs and making more efficient the production of renewable energy.

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