ON DEFECT SIZING TECHNIQUES IN STEEL COMPONENTS

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Martínez-Oña, Rafael
Tecnatom, S.A.
Avda. Montes de Oca, 1
28709 San Sebastián de los Reyes, Madrid
Spain
Tel.: +34.91.6598657
Fax: +34.91.6598677
E-mail: rmo@tecnatom.es

ABSTRACT

Ultrasonic Non-Destructive Examination (NDE) is currently utilised to assess the integrity of industrial components. For certain applications such as in the nuclear industry, when a defect is found, a quantitative determination of its size is sought to allow a precise structural integrity study and life assessment. In recent years, a number of ultrasonic inspection techniques have been developed in order to measure length and depth of detected defects. Those techniques based on signal amplitude exhibit a number of shortcomings for depth sizing of cracks while techniques based on diffraction of signals are providing good results. In this paper, first, are described the main characteristics of ultrasonic techniques for inspection of steel components, then, follow examples of their application in real configurations.

INTRODUCTION

Life assessment analyses are currently applied to assure safety, optimise the availability of industrial plants and minimise the presence of non planned outages. These analyses and others of structural integrity require to know the size of defects. These studies are extremely important when considering nuclear power plant components because safety is a must and replacement of a component that may have a defect can be time consuming and difficult.

Ultrasonic techniques allow to inspect metallic components detecting the presence of defects and their size. However, there is a number of factors that influences the performance and reliability of inspection results. This requires to use the applicable technique for the specific problem. It is known that methods based on the reflected amplitude are strongly influenced by the defect type, by the orientation related to the sound propagation, by the transducer frequency and by others. On the contrary, methods based on the diffracted amplitude are much less influenced by either the defect morphology or defect orientation. Nevertheless, parameters such as type of material, geometry of the component, deployment system and others have to be taken into account to achieve the desired performance. Nowadays current practice is the qualification of the NDE system to ensure it is capable of achieving the required performance under real inspection conditions.

Along this paper, due to their impact for life assessment, when referring to defects it would mean in service induced defects; these correspond to any type of crack either planar like or branched.

FACTORS INFLUENCING INSPECTION

Three main factors may influence the performance of the ultrasonic inspection: component to be inspected, inspection equipment and ultrasonic probe. Regarding component, its structure being carbon steel (isotropic) or austenitic steel (anisotropic) conditions the propagation of the ultrasonic waves; on the one hand, carbon steel can be easily inspected but, on the other, austenitic steel or cladding produce beam skewing, scattering and strong attenuation of ultrasonic waves that require the application of specific techniques to overcome these limitations. Component geometry, access to the inspection surface, and environmental conditions also difficult the ultrasonic inspection; in particular, for examining nuclear components it is necessary to use mechanical equipments to scan the transducers remotely and automatically on the inspection surface.

Inspection equipment refers to mechanical equipment, ultrasonic flaw detector and data acquisition and analysis system. Of these, mechanical equipment may have a strong influence on the inspection results due to the movement and location of transducers for defect sizing. These equipment are installed remotely to scan complex inspection areas such as a cylinder or a torus with high accuracy and repeatability (of the order of half a mm). Functional tests are normally carried out to measure its uncertainties and compensate then accordingly.

Ultrasonic transducer main error sources can be beam exit point and beam angle determination. In addition to this, as pointed out above, beam angle can be skewed by anisotropic structure. All these error sources should be taken into account during the sizing process to compensate their effects.

INSPECTION TECHNIQUES

Ultrasonic inspection can be considered a two steps process: detection and sizing. Detection techniques would provide reliable answers thus giving clear information about the integrity of the component (presence or absence of defects); these methods will have a high probability for defect detection related to a high signal to noise ratio. Although the specific technique to apply depends on the geometry of the component, access and type of expected defect, for most of the cases, detection methods are based on reflection phenomena because these generate more energetic signals than diffraction phenomena. Additionally, for practical considerations, the technique would be easy to implement, fast and robust.

The objective of sizing techniques is to characterize the size of existing defects to provide an input to structural integrity calculations. For these techniques, the important defect dimensions are its length and through wall extension (see figure 1). It exists a large number of defect sizing methods, however, according to their main principles, the two most important will be presented.

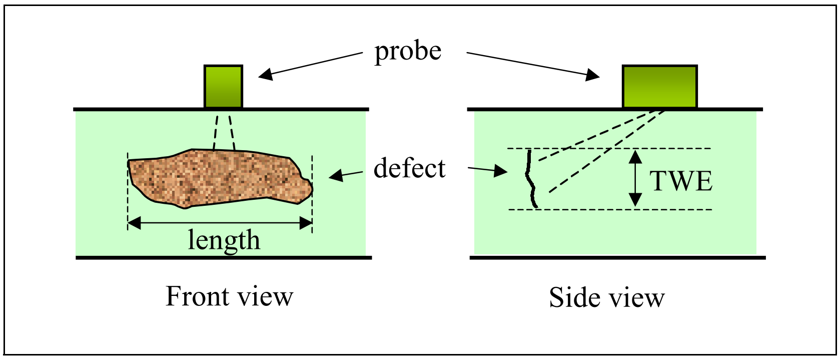

Figure 1. Characterisation of a defect

Tip Diffraction Sizing Techniques

Diffraction effects are due to the wave nature of sound. Diffraction means modification or deflection of the sound beam by objects. Any obstacle placed in the sound path will cause diffraction. The effect is strongest for objects with sharp edges such as cracks. Tip signals can be located accurately, providing a direct measure of the defect size. The time of flight to the tip signal is used to compute the defect size. Tip diffracted signals are usually much weaker than the directly reflected signal, however, these can be detected reliably if probe features are adequately selected and the instrumentation has enough amplification [1].

Backward scattering method

The transducer acting as transmitter and receiver is scanned across the inspection surface to find defect tips (see figure 2). The defect transit times (called time of flight) are measured for the top and bottom tip signals. The transit times are converted to depth through according to

$$z = v \cdot t \cdot \cos\vartheta$$

where z is the depth below scanning surface, t is the transit time and ϑ is the probe beam angle. These probe parameters shall be accurately determined to minimize measure uncertainty.

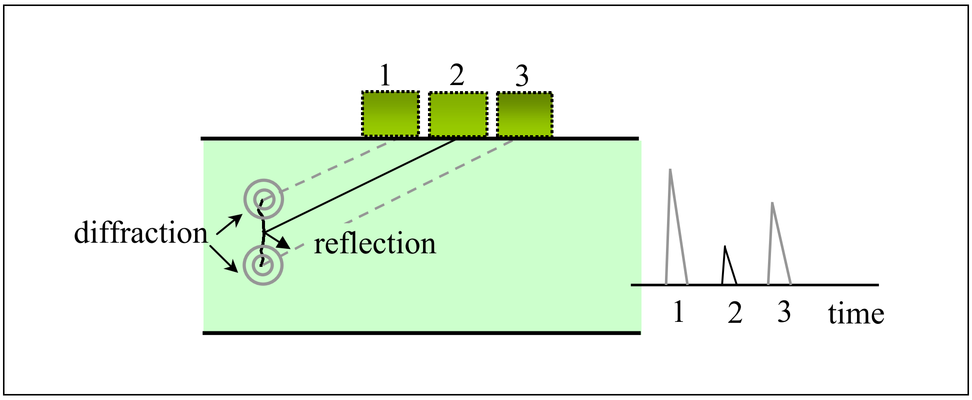

Figure 2. Principle of backward scattering method

Forward scattering method with two transducers (TOFD)

This is also named time of flight diffraction technique. In this technique, one transducer acts as transmitter and the other as receiver and maintain a fixed distance. In addition to the main longitudinal wave generated that produces the tip signal, a lateral wave is produced that travels close to the surface. A backwall signal can be observed if the material is thin enough for one of the wave components to reach the receiver after reflecting off the bottom of the test piece (see figure 3).

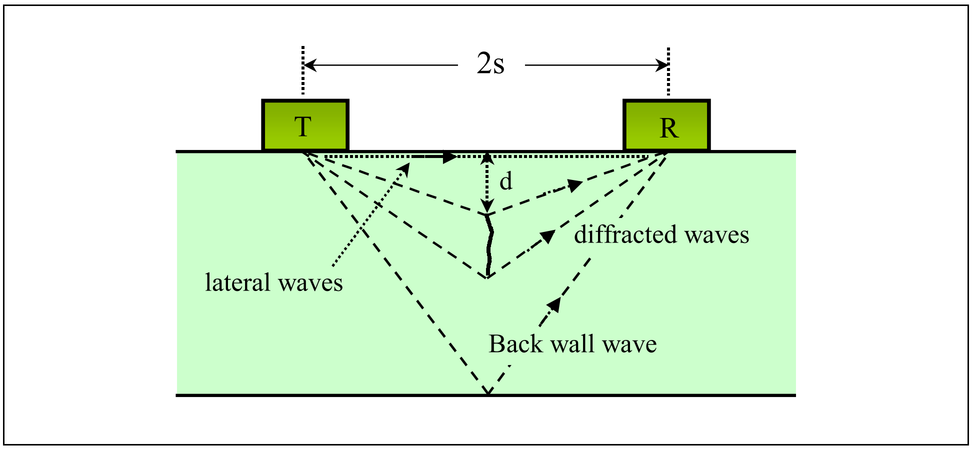

Figure 3. Principle of TOFD technique

The transit time for a tip signal at a depth *d* below the surface is [1]

$$t = \frac{2\left(s^2 + d^2\right)^{1/2}}{v} + 2 \cdot t_0$$

where v is the longitudinal wave velocity, s is half the transducer separation, and t_0 is the time delay in the probe shoes. From this equation, depth can be obtained as a function of t. If the lateral wave is observable, the velocity v in the above expression can be replaced by $4s/t_l$, where t_l is the transit time of the lateral wave.

Advantages of tip diffraction techniques

These techniques use the tip diffracted signals, not the main reflected wave to size the defect. Amplitude based methods depend on many conditions unrelated to defect size; surface roughness of the flaw, its tilt, skew and position; coupling quality, etc. Since diffracted waves from the defect tips spread over a wide angular range, they can be easily detected, with little regard to defect orientation. Because diffracted waves from the top and bottom tips of a crack have different phases, they are able to differentiate closely spaced flaws.

Decibel Drop Sizing Techniques

The transducer is positioned to obtain the maximum amplitude signal from the defect. From this position, the transducer is moved until the signal drops to a certain threshold level. This position is assumed to be over the flaw edge. By scanning the transducer over the maximum amplitude position, the defect can be mapped. The transducer beam would impinge on perpendicularly to the defect. If the transducer is positioned so that the beam centreline intersects the defect edges as in the figure, the probe lateral movement *s* is related to the defect vertical height *d* as:

$$d = \frac{s}{tg\vartheta}$$

where ϑ is the transducer beam angle (see figure 4). Different amplitude threshold have been suggested (6, 12, or 20 dB lower than the maximum signal, noise level, etc.). Each threshold level can be used effectively according to the morphology of the flaw.

Planar defects larger than the transducer beam and perpendicular to its centreline can be adequately sized with this technique. For defects smaller than the probe beam diameter, beam spread corrections are necessary; on the other hand, these corrections are difficult and introduce errors.

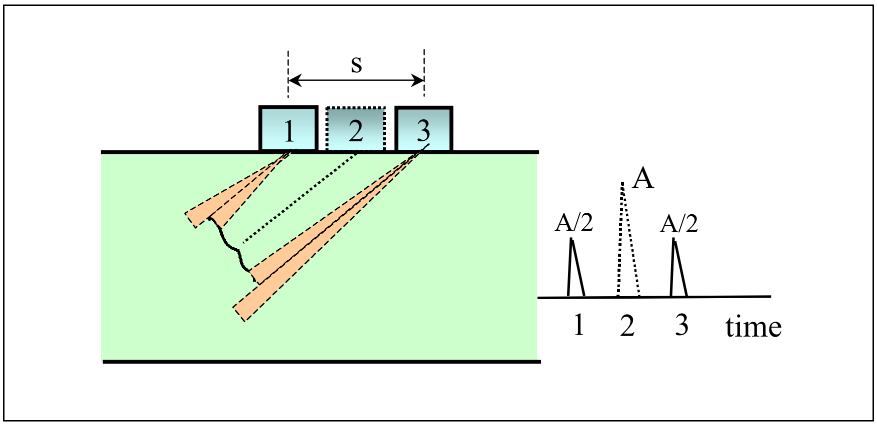

Figure 4. Principle of dB drop technique

Applying Focused Probes

Using focused transducers overcome some disadvantages of conventional probes. Focusing produces an intense and sensitive beam with high lateral resolution. Backward diffraction technique can benefit of using focused transducers because in the focal zone energy concentrates and diffraction signals exhibit higher sensitivity improving the signal to noise ratio. DB drop method also improves results due to the high lateral resolution of focus probes.

Focal length *l* and diameter *d* of the focal zone are related to the transducer diameter *D*, frequency *f* and focal depth *F* as follows [3]

$$l = 4 \cdot \frac{v}{f} \cdot \left(\frac{F}{D}\right)^2 ; \quad d = \frac{v}{f} \cdot \frac{F}{D}$$

where *v* is the sound velocity. From these equations, it is shown that a large diameter transducer is required to achieve a small diameter at great depths. Focusing of the sound field can be accomplished in a number of ways; commonly, by: curved transducer element, lens, dual elements, and phased arrays. However, these general principles apply for the different designs.

RESULTS

Examples of the above mentioned techniques are shown in this section. In occasions, due to the anisotropic structure of the material examined and to the crack type defect morphology, the analysis of the results requires an in depth knowledge of the technique to overcome the limitations present.

In figure 5 it is shown an example of an intergranular stress corrosion crack in 304 austenitic stainless steel, 35mm thickness, detected and sized with a by-crystal shear wave 2MHz, 45° angle focused probe. The anisotropic structure of the material, the weld configuration (which present weld crown, root and counterbore), and the crack small depth impede to use a diffraction based method.

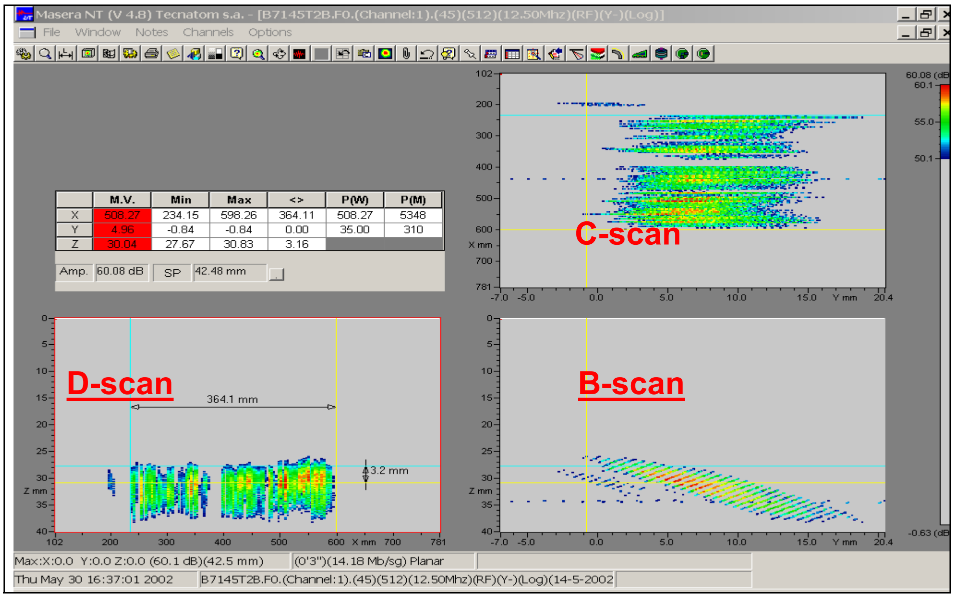

Figure 5. Example of intergranular stress corrosion crack sizing

Amplitude drop method has been used for crack sizing. The first step is to discriminate defect signal from geometric indications; after that, sizing measurements are made on defect signals. Length is obtained by measuring defect signal at noise level as shown in Figure 5 D-scan. Depth is calculated by 6dB drop of the maximum amplitude, refer to Figure 5 B-scan. Maximum amplitude comes from reflection signals of crack corner.

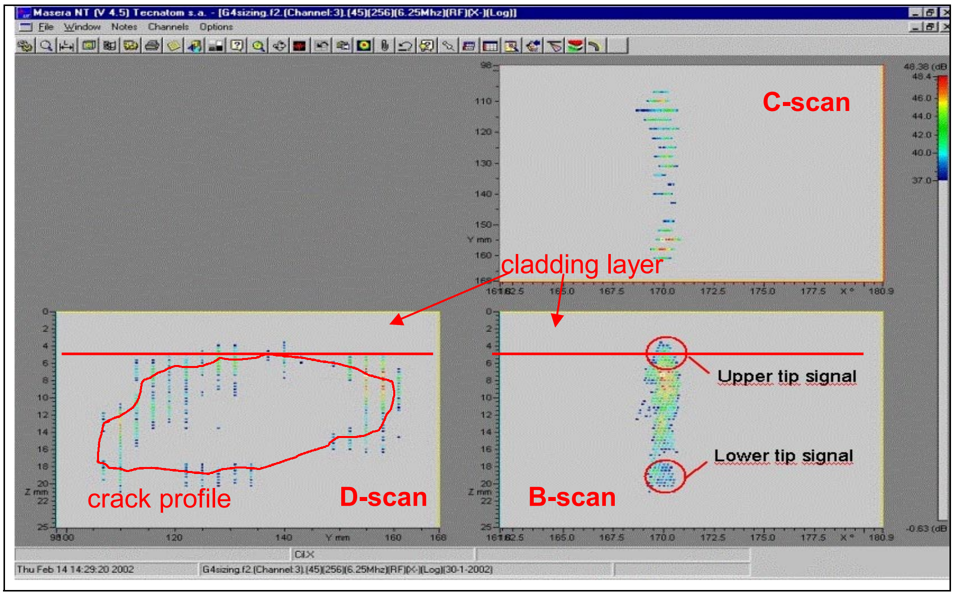

Figure 6. Image of a fatigue crack by backward diffraction method

An example of backward diffraction technique is included in Figure 6. It shows a fatigue crack located under a 5mm cladding layer in a ferritic pipe. These results are obtained with a by-crystal longitudinal wave 2MHz, 45° angle focused probe. In the side view (B-scan), upper and lower tip crack diffractions are shown; identifying diffractions in each slice, crack profile can be mapped (see D-scan).

An example of forward diffraction or time of flight diffraction (TOFD) technique is presented in Figure 7. The side view shows depth along axis X and probe displacement in axis Y; below it is included the A-scan. The image corresponds to the inspection of a cylindrical piece with embedded artificial planar defects; three of them are clearly visible. From left to right, it appears the lateral wave, the defect upper tip, and the backwall echo. A correspondence between A-scan tip diffraction and backwall echo, and side view signals must be obtained.

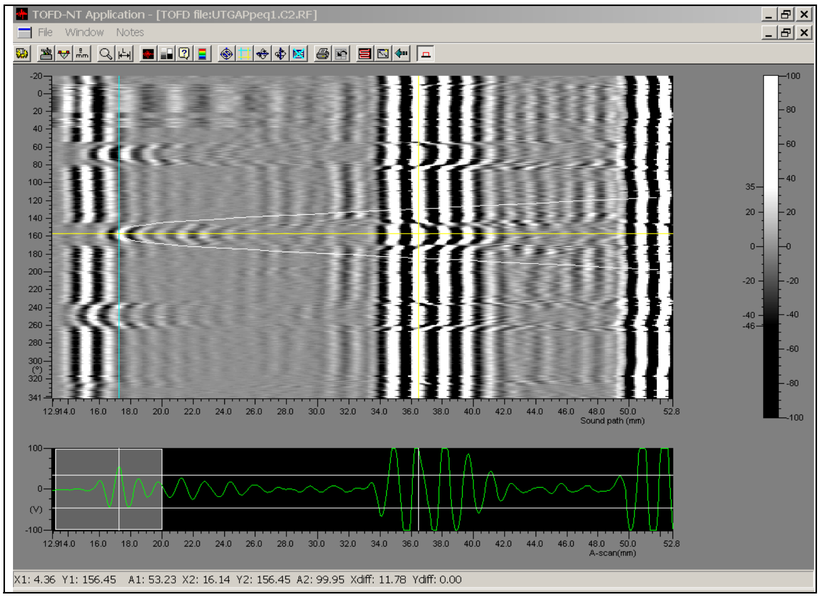

Figure 7. TOFD technique sizing an artificial planar reflector

The interpretation and measurement on TOFD images are more difficult when anisotropic material is examined, because the sound velocity is different for lateral wave and diffracted wave; sizing errors can be important for small cracks in the claded area [2].

CONCLUSIONS

Defect sizing is very important to perform structural integrity assessment. It exists different ultrasonic sizing techniques based on signal amplitude or diffraction signals. These ones achieve better accuracy for depth sizing than those techniques based on signal amplitude. Their principles have been described and, after that, examples of crack sizing have been presented.

REFERENCES

[1] Accuracy of Ultrasonic Flaw Sizing Techniques for Reactor Pressure Vessels, EPRI Report NP-6273, March 1989.

[2] *A. Erhard, R. Boehm, U. Tessaro, H. Wüstenberg*; Characterization and Sizing of Defects in the Claded Area using Ultrasonic Methods; Proceedings of the 3rd International Conference on NDE in Relation to Structural Integrity for Nuclear and pressurised Components, Seville, November 14-16, 2001.

[3] *R. Saglio, A. C. Prot*; Ultrasonic Focusing Techniques; in “Research techniques in non-destructive testing”, vol. 8, R. Sharpe editor; Academic Press, London, 1985.