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NONLINEAR IMAGING OF CLOSED CRACKS BY A FUNDAMENTAL WAVE AMPLITUDE DIFFERENCE APPROACH

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ABSTRACT

Characterization of cracks and crack propagation is of great importance in many industrial fields such as oil and gas, power generation or transportation industries. In particular, stress corrosion cracking (SCC) is a challenging issue in these industries. Conventionally, sample integrity is controlled by phased array ultrasonic testing because of its ease of use. In reality, this nondestructive testing (NDT) technique, considering linear acoustic assumptions, only reveals the opened parts of cracks. This leads to an underestimation of the crack depth because real cracks often contain closed parts and ramifications. Methods considering nonlinear effects or revealing these effects have shown to be appropriate to characterize closed parts of cracks. In this paper, we propose to use a nonlinear imaging method based on a fundamental wave amplitude difference approach. The purpose is to generate several conventional focused sequences with different power amplitudes. Then, the nonlinear image is obtained by subtracting images together, giving a nonlinear residue. This method is assessed with a fatigue crack obtained by mechanical fatigue cycles. It has been implemented in an open ultrasound platform that makes this inspection in real-time. It results that both linear and nonlinear images give complementary information. The linear images reveal opened parts of the cracks and nonlinear images gives information about the closed parts.

Keywords: ultrasonic imaging, nonlinear scatterers, phased array, fatigue crack, thermal crack, stress corrosion cracking

1. INTRODUCTION

Ultrasonic testing (UT) with phased array is a standard process for controlling the structural integrity of critical industrial parts in many demanding fields (oil and gas, power generation, aircraft industry, etc.). In particular, it is employed for the detection and characterization of cracks that can be created by fatigue, heat or stress corrosion. Crack depth is usually measured by conventional UT (which is based on linear acoustic assumptions). This modality is actually sensitive to the opened parts of cracks since ultrasonic waves are reflected and/or scattered because of significant impedance change. On the contrary, closed parts are invisible to conventional imaging due to the lack of impedance rupture which cannot generate sufficiently large echo to be detected with conventional UT [1]. This results in a crack length underestimation because cracks contain opened and closed parts.

It is known that nonlinear acoustic methods are appropriate to detect and characterize partially-closed and closed cracks [2]. Usually, nonlinear techniques detect subharmonic and superharmonic components [3], that are generated by nonlinear effects between the waves and the flaw (clapping, friction, slipping). In this paper, we propose to use a method based on the fundamental wave amplitude [4]. The method is called fundamental wave amplitude difference (FAD) has been proposed and studied for crack characterization in [5,6]. The principle is to generate several focused sequences with different power amplitudes and then to subtract images together in order to get a nonlinear residue.

In this paper, we propose to give an overview of the method and an application to a fatigue crack characterization. Technical and technological aspects will be detailed in the scope of a use of the method in real applications.

2. MATERIALS AND METHODS

Fundamental wave amplitude difference (FAD) imaging has been described in [5,6]. The standard process consists in performing a first linear scan at a given focal depth with a phased array probe. It results in the linear image denoted $\boldsymbol{O}_L$, that is the reference linear image. Then the sequence scan is effected by taking the even elements for firing, which is equivalent to take half the power compared to the first scan, giving image $\boldsymbol{O}_e$. Finally, the odd elements are firing, giving image $\mathbf{O}_o$. The non linear image is obtained by subtraction between the "full" and the "half" images such as:

$$\mathbf{O}_{NL} = \mathbf{O}_L - \mathbf{O}_e - \mathbf{O}_o. \quad (1)$$

If the propagation medium contains only linear scatterers, all linear contributions are cancelled and the nonlinear image is null. On the contrary, if it contains nonlinear scatterers, $\boldsymbol{O}_{NL}$ is not null and composed of nonlinear residue present in the linear image. The information given in this image corresponds to the fundamental frequency that is why it is called fundamental wave amplitude difference method.

The advantage of this method is that it can be implemented on a standard UT device using a fixed voltage pulser. It has been implemented in the open ultrasound platform Pioneer (The Phased Array Company, West-Chester, Ohio, USA). The following results are obtained with a linear probe of 128 elements, center frequency 5MHz and pitch 0.5mm (Imasonic, Voray-sur-l'Ognon, France). The probe is placed directly in contact on an aluminum square bar (see Figure 1). This sample contains a crack that has been created by mechanical fatigue from a machined notch. This crack contain an open part and a closed part in the upper direction.

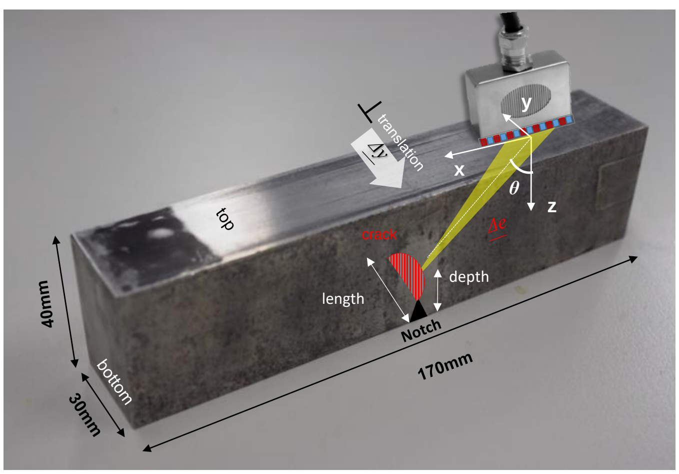

Figure 1. Schematic of the inspection (extracted from reference [6]). The phased array probe is placed in contact, steering the beam in the notch direction.

3. RESULTS AND DISCUSSION

The sample containing a fatigue crack is inspected from the top of the sample with the probe placed in contact with coupling gel. A mechanical scan is performed in the y direction in order to observe several positions of the crack. The results are given in Figure 2. For several positions, indications are given by linear imaging (in red), by nonlinear imaging (in blue) and by both linear and nonlinear imaging (in yellow). We can notice that linear indications mostly concern the top of the notch and the tip of the crack

(around depth 20mm). Nonlinear indications show mostly information upper than the linear tip, which we strongly suspect to be closed parts of the crack. Some positions, like y=6mm, shows mostly nonlinear indications, which means that this part contains sensitive nonlinear scatterers such as closed cracks. It is noticeable that linear and nonlinear methods show complementary indications.

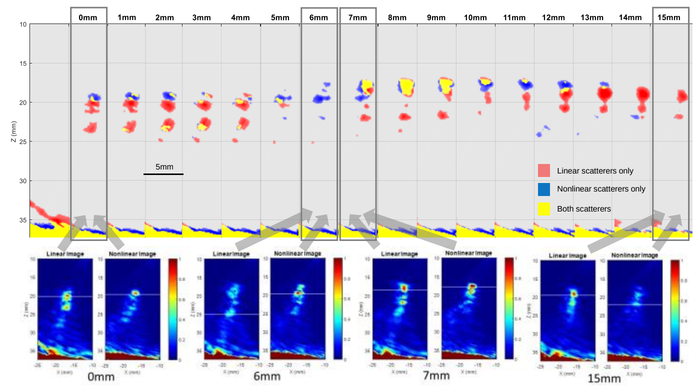

Figure 2. Linear and nonlinear images for several scan positions in the Y direction (extracted from reference [6]).

4. CONCLUSION

In this paper we have recall the principle of nonlinear imaging based on a fundamental wave amplitude approach. The method is applied for the characterization of cracks. The given example is about the inspection of an aluminum bar containing a mechanical fatigue crack. We showed that linear imaging gives indication about the open parts of the crack. On the other hand, nonlinear imaging shows upper indications, that are likely linked to the closed part of the crack. Both indications are complementary. In real applications, nonlinear imaging could be used as refinement in some critical regions.

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