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2D SIMULATION OF ULTRASONIC INSPECTION OF WELD JOINTS WITH DEFECT USING FINITE ELEMENT METHOD

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ABSTRACT

An Ultrasonic simulation model uses physical equations and numerical methods to predict the result of an experiment. Because it is a software model, any parameter that effects the results can be changed or varied as needed. One important motivation for using such models is the relatively low cost of software predictions compared to the cost of comparable experiments. The simulation of ultrasonic testing using appropriate models allows to perform parametric studies and to obtain quantitative simulated results. In this paper, authors used Finite element analysis software and designed some defects which have different types of dimension and depth in weld, more creditable message about defect is obtained qualitatively and quantitatively. The emphasis is placed on the relationship between the type, dimension and position of defect. The aim of this paper is to model and investigate the behavior of the propagation of ultrasonic waves through a previously published and well established weld model, in order to facilitate improvements to practical aspects and to the methodology of current weld inspection.

Keywords- Ultrasonic Testing; Wave Propagation,Phased array.

I. INTRODUCTION

Finite Element Method is a numerical tool using which such simulations can be done effectively. Features of wave propagating in a domain depend on various properties like density, modulus of elasticity, Poisson's ratio and loading. As FEM divides the domain into numerous small elements and forms element equation for each of them, modeling of composite domains with multi properties can be adeptly handled. Responses at different locations due to prescribed excitation are simultaneously available through solution of the assembled equations.Simulation of a technique is used to predict the expected experimental results where experiments are very costly or are difficult to conduct. Modelling studies play an important role in:

- Obtaining physical insight of the problem.
- Optimisation of experimental parameters for effective testing and
- Conducting benchmark studies

The interpretation of experimental data, particularly when complex signals are encountered.Ultrasonic testing is based on time-varying deformations or vibrations in materials, which is generally referred to as acoustics. All material substances are comprised of atoms, which may be forced into vibration motion about their equilibrium positions. Many different patterns of vibration motion exist at the atomic level. However most are irrelevant to acoustics and ultrasonic testing. Solid molecules can support vibrations in other directions. Hence a number of different types (modes) of sound waves are possible. As mentioned previously longitudinal and transverse (shear) waves are most often used in ultrasonic inspection. However at surfaces and interfaces, various types of elliptical or complex vibrations of the particles make other waves possible.

When a wave is traveling in any material, the energy of a wave will be absorbed or attenuated by the material. The attenuated rate is due to the material properties and boundary conditions of the test specimen. When we compare the output waveform of actual experimental results with FEM results, it is found that the attenuation of FEM output waveform will be much lower than the experimental one. When a disturbance (stress or displacement) is applied suddenly at a point on the surface of a solid, such as by impact, the disturbance propagates through the solid as three different types of stress waves: a P-wave, an S-wave, and an R-wave. The P wave and S-wave propagate into the solid along spherical wave fronts. The P-wave is associated with the propagation of normal stress and the S-wave is associated with shear stress. In addition, there is an R-wave that travels away from the disturbance along the surface. Surface or Raleigh waves travel the surface of a relative thick solid material penetrating to a depth

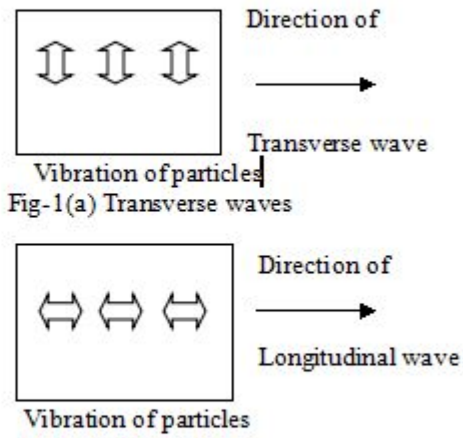

Fig-1(b) longitudinal waves

of one wavelength. Rayleigh waves are useful because they are very sensitive to surface defects and since they will follow the surface around, curves can be used to inspect areas that other waves might have difficulty in reaching. Plate waves can be propagated only in very thin metals. Lamb waves are the most commonly used plate waves in NDT. Lamb waves are a complex vibration wave that travels through the entire thickness of a material. With lamb waves, a number of modes of particle vibration are possible, But the two most common are symmetrical and asymmetrical.
This paper pointed out that when the specimen under investigation has a complex geometry, as in the case in many real applications, only numerical approaches are useful for simulating multiple
reflections and scattering of the ultrasonic waves within the specimen. A series of publications by Ludwing and Lord [2] studied finite element simulation of ultrasonic wave propagation and
their interaction with defects. This paper uses
a dynamic explicit time integration scheme.
Simulation of the Pulse- echo technique involves simulation of A-scan signals, which consist of reflection/diffraction of different wave modes (lateral wave, diffracted wave(s) from the defect tip(s) and back wall).

II. BACKGROUND

Ultrasonic inspection is one of the most widely used methods of nondestructive inspection. Basically ultrasonic inspection is done by propagating high frequency sound waves (0.1-25 MHz) into the material for the detection of surface and subsurface flaws in that material. Ultrasonic waves are basically mechanical vibrations; the amplitudes of vibrations in metal parts being ultrasonically inspected impose stresses well below the elastic limit, thus preventing permanent effects on the parts.

Most of the ultrasonic inspection instruments detect flaws by monitoring one or more of the following:

- Reflection of sound from interfaces consisting of material boundaries or discontinuities within the metal itself
- Time of transit of a sound wave through the test piece from the entrance point at the transducer to the exit point of the transducer
- Attenuation of sound waves by absorption and scattering within the test piece
- Features in the spectral response for either a
transmitted or a reflected signal.

The principle of the FE method is to solve problems by replacing a large and complex structure with a number of smaller and simpler structures. It is also applied where the original structure may not be complex but events that take place within are complex.

Simulation of the pulse echo technique using FEM has not been reported in the literature. This is attempted in the current work. The finite element package Abaqus is used in the current work to model the propagation of ultrasonic waves in a thin cracked two-dimensional geometry. Abaqus uses the explicit Newmark'salgorithm to solve the wave equation. Various solution options that were used from Abaqus are listed in Table 1.

Table 1. Abaqus features used in the FEM analysis

Abaqus	Description
Multiphysics	Transient dynamic analysis
Dimensionality	Plane strain
Solution	FEM solver with applied loads

III. ULTRASONIC FLAW DETECTION

This technique is used for the detection of internal and surface (particularly distant surface) defects in sound conducting materials. The principle is in some respects similar to echo sounding. A short pulse of ultrasound is generated by means of an electric charge applied to a piezo electric crystal, which vibrates for a very short period at a frequency related to the thickness of the crystal. In flaw detection this frequency is usually in the range of one million to six million times per second (1 MHz to 6 MHz). Vibrations or sound waves at this frequency have the ability to travel a considerable distance in homogeneous elastic material, such as many metals with little attenuation. The velocity at which these waves propagate is related to the Young's Modulus for the material and is characteristic of that material.
There are several factors that affect whether a given flaw can be detected, among them, are the following:

- The type of flaw and its orientation
- The depth of the flaw
- The contact time of the impact

In addition, it is necessary to make a distinction between being able to "detect" the presence of a flaw and being able to determine the depth of the flaw. As the depth of a flaw increases, the smallest size that can be detected also increases.

IV. SIZING OF FLAWS

To establish the ultrasonic technique completely knowledge of its accuracy in both sizing and indicating the flaw type is essential. The flaw size, type and accuracy are dependent upon the casting thickness, or whether the casting walls are planar (linear) or rounded. The flaw size is to be detected by magnetic particle, dye penetrant, radiographic and ultrasonic techniques.

Once flaws have been detected it is often desirable to determine their size. For flaws smaller than the ultrasonic beam width, a pseudo-sizing can be obtained by comparing the flaw signal amplitude with that of a reference reflector (flat-bottomed or side-drilled hole) at the same range. When the flaw size is greater than the ultrasonic beam width, conventional probe movement sizing techniques can often be used to provide an estimate of flaw size. The maximum amplitude technique uses a measure of the probe movement between the maximized signals from flaw extremities to size flaws.. However, the interaction between the ultrasonic beam and flaw, depending as it does on flaw nature and orientation, limits the effectiveness of these techniques, when dealing with complex and mis-orientated flaws. The flaw type is specified in terms of its shape (linear, planar, or rounded).
A second important aspect is how far apart two flaws would be located before they could be resolved the value is of the order of 10 mm. However, further research is essential to determine the accuracy of the ultrasonic technique in many different situations. The currently available ultrasonic methods of assessing flaw size are the maximum amplitude and beam spread techniques.

V. MODE CONVERSION

When sound travels in a solid material, one form of wave energy can be transformed into another form. For example, when longitudinal wave hits an interface at an angle, some of the energy can cause particle movement in the transverse direction to start a shear (transverse) wave. Mode conversion occurs when a wave encounters an interface between materials of acoustic impedance and the incident angle is not normal to the interface. Since mode conversion occurs every time a wave encountered interface at an angle, ultrasonic signals can become confusing at times.

VI. PULSE-ECHO TECHNIQUE FEM MODEL

An ultrasonic (NDT) method for the detection and characterization of defects in composites in which pulses are transmitted and received on the same side of the test panel after being reflected from the opposite face. Defects cause a decrease in the reflection amplitude. From the measurement of the time of occurrence, the defect signal, the signal amplitude and its frequency spectrum, the axial location and
severity of the defect is determined. This method is called the pulse-echo technique.Modelling the Pulse-echo technique involves (a) modeling the specimen geometry with defect.
(b) Modeling the piezoelectric transducer. Each of these modeling features is described in detail below.

(a) Modeling the geometry with defect

A simple flat specimen with vertical and inclined Electrical Discharge Machined (EDM) notches is modeled as different areas (2-D) and the defect is modeled as an area without elements.
The entire area is discretised into mapped mesh (quadrilateral structured mesh) with (2-D plane strain) elements with a spatial resolution of $\lambda/12$ where 'λ' is the wavelength. This spatial resolution was chosen after detailed convergence studies, so as to obtain stable solution.

(b) Modeling the transducer

The actual piezoelectric mechanisms can be modeled by the appropriate transient excitation pulse on the surface of the material.
The pulse that is normally used in ultrasonic simulation [9, 10] is given in Equation 1 and is plotted in Figure 2 for 3 cycles and 5 MHz.

$F(t)=\{[1\cos(2\pi ft/3)]\cos(2\pi ft),for0<t<3.0/f$……(1)

otherwise

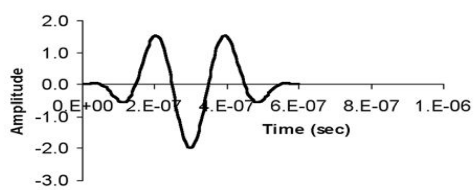

Figure 1. Equivalent force for a 5 MHz with three cycles piezoelectric transducer modeling
central frequency transducer. This force is applied on the nodes that are located at the interface of transducer and the specimen. The line of contact between transducer and specimen was modeled as using a number of point forces acting on the specimen.

VII. PHASED ARRAY METHOD

In wave theory, a phased array is an array of antennas in which the relative phases of the respective signals feeding the antennas are varied in such a way that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions. An antenna array is a group of multiple active antennas coupled to a common source or load to produce a directive radiation pattern. One common application of this is with a standard multiband television antenna, which has multiple elements coupled together. Phased array (PA) ultrasonic is an advanced method of ultrasonic testing that has applications in medical imaging and industrial nondestructive testing. The PA probe consists of many small ultrasonic elements, each of which can be pulsed individually. By varying the timing, for instance by pulsing the elements one by one in sequence along a row, a pattern of constructive interference is set up that result in a beam at a set angle. In other words, the beam can be steered electronically. The beam is swept like a search-light through the tissue or object being examined, and the data from multiple beams are put together to make a visual image showing a slice through the object.

A-scan signals were collected for particular positions of a receiver in the sample with defect as shown in Figure 2(a). and without defect as shown in Figure 3b). The location and orientation of transmitter position 'T' and receiver position 'R-1'are similar to flat plate with vertical surface notch. The back wall echo is used as reference echo because of the absence of lateral wave. Multiple probe elements produce a steerable, tightly focused, high-resolution beam.

Transducer properties:	
Central frequency	5 MHz
Number of Cycles	3
Type of transducer	Longitudinal
Time step size	2e-8
Discretization parameters:	
Transducer length	15 mm
Element size	0.1 mm (λ/12)
Total number of nodes	1,26,326
Total number of elements	1,25,318
Element type	4 noded 2-D plain strain element with mesh
Total computational time	2 hours in a 1 GB RAM, P4 system
Material properties:	
Young's modulus	70.3 Gpa
Density	2.73 Kg/mm^3
Poisson's ratio	0.33

VIII. SIMULATION OF VERTICAL DEFECT

Pulse-echo signatures were simulated for an aluminium plate of 5 mm thickness with EDM notches (0.4 mm width) of lengths for a 30 degree probe angle. Figure 2(a) and 3(a) shows Abaqus snapshots (*uy* displacements) at a particular time step. When the force is applied on the surface, the waves generated are longitudinal wave, shear waves, and head waves are generated inside the material. Lateral waves and Rayleigh waves are generated on the surface of the material. These waves can easily be detected in the FEM simulated snapshots shown in Figure 2(a) and 3(a).Since the diffracted amplitudes are very much less in amplitude compared to refracted shear wave inside the material, the scale in the snapshots is adjusted to highlight the diffracted wave from the defect.

Table 2. Transducer, discretization and material parameters

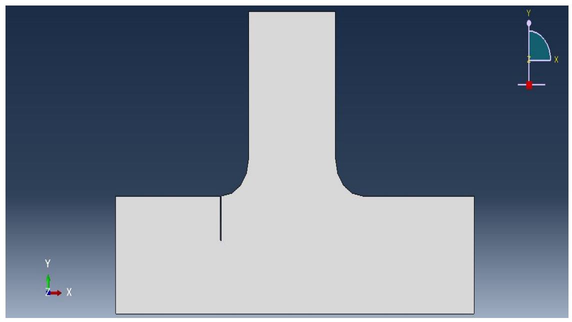

Figure 2. T-butt weld with (a) vertical crack

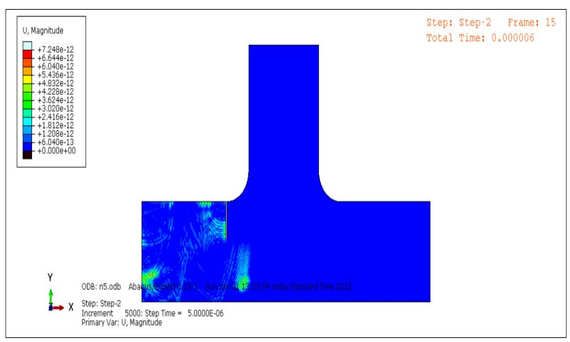

Figure 2(a). Snapshot of wave interaction with vertical defect at time step (a) 2.4e-6

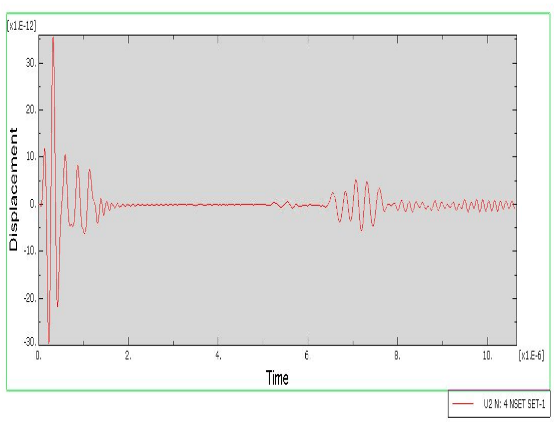

Figure 2(b). 2-D FEM Simulation of A-scan signal from defect of size

IX. SUMMARY

The pulse echo technique has been simulated using 2-D FEM. The angle beam transducers are modeled by applying linear delayed forces at the surface. The simulated results are compared for samples with defect and without defect and were found to be in good agreement with each other. The application of the pulse echo technique to inspect complex T-butt welds was also simulated using 2-D FEM. The possible probe positions to inspect an entire region of T-butt welds are obtained for the T-butt weld.

The average computational time for the example cases are 1h in a 2GB RAM computer. To reduce the computational time, advanced simulation techniques like spectral element methods can be used.

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