A REVIEW OF APPLICATIONS OF ULTRASONIC TECHNIQUES IN PETROLEUM INDUSTRY

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ABSTRACT

Ultrasound, as an emerging green technology has received increasing attention of the petroleum industry. The diversity of ultrasound techniques used in oil and gas pipeline plants provides us with a wealth of information on how to exploit this technology when combined with other techniques, in order to improve the quality of analysis. The fundamental theory of ultrasonic nondestructive evaluation (NDE) technology is offered, along with practical limitations as related to two factors (wave types and transducers). This review paper presents applications and limitations of some ultrasonic techniques. The paper demonstrates the fundamental theory of ultrasound and type of waves used and examines the inspection approaches of the contact and angle beam techniques. This review also clarifies and discusses the options used in solving the industrial engineering problem, with a comprehensive historical summary of the information available in the literature. Merging various NDE inspection techniques into the testing of objects is discussed.

Keywords: *Ultrasonic Testing, Guided Waves, Pipe Inspection, Pipe Thickness*

I. INTRODUCTION

Ultrasonic testing is one of the important techniques of nondestructive testing (NDT). It uses ultra-high-frequency sonic energy to locate and identify discontinuities in materials that are both on and below the surface of the material (such as metals or plastic, commonly used to make pipes, depending on the application) [1]-[5]. In 2007 D. S. Caravaca et al. [6] studied polyethylene pipe joints and detection of improper preparation of the joints using a phased array technique (PAT). The problems that arise with the electrofusion type of bonding used for the pipe are analogous to those that occur in metal welds for steel pipe. This paper aims to offer an ultrasonic method for evaluating polyethylene pipe welds, in pipeline used for gas and water distribution, along with results from both laboratory and field experiments [6].

The sonic energy passes through the substrate. There is a reduction in energy intensity, as well as reflection of the waves by the back wall of the material, and where discontinuities are encountered. The returning signal is captured, mathematically analyzed and presented on a screen, with the resultant waveform showing the location of defects on or within the substrate [7]-[11].

In 2006, Yi-Mei Mao and Pei-Wen Que investigated the possibility of using a then-new sonic signal processing method for inspection of oil pipelines. They compared “ultrasonic signals reflected from defect-free pipelines and from pipelines with defects” [12] and treated the recaptured waveforms with the Hilbert-Huang transform (HHT). The results demonstrated the feasibility of using the technique to successfully locate and determine the extent of discontinuities in oil pipes [12].

Reflected signals are attenuated to different degrees depending on the type of interface they encounter. An interface between a metal and a liquid presents a reduced reflection of the sonic energy, whereas an interface between a gas and a metal causes nearly 100% reflection of the sonic waves [7]. The actual percentage of reflection is dependent on the ratio of the parameters of certain physical properties between the two types of material, for example, the ratio between the metal and the liquid substance at the interface [13]-[16].

Cracks, holes, laminations, slags, cavities, porosities, bursts, lack of fusion, flakes, lack of penetration and other discontinuities that produce sharp boundaries are easily identified by ultrasonic testing. Other types of discontinuities that produce a more diffuse boundary are still identifiable because they will disrupt the sonic waves in a detectable manner [7] [17].

In 2015, Wissam Alobaidi et al. surveyed seven types of defects commonly found in pipe joint welds, and five often-used types of welds in manufacturing. The correlation between each defect type and the NDT technologies which best reveal the defects is presented in a table [17]. The ability and shortcomings of four NDT techniques commonly used for testing pipe are compared, one of which is ultrasonic testing, and the table reports whether each technique can detect surface, or subsurface flaws. The paper examines ways in which new quality assurance techniques can be incorporated alongside the standard methods in order to overcome the shortcomings of current methods, with the aim to reduce labor costs and increase line output [17].

Because the sensing mode of ultrasonic evaluation is a mechanical process, the frequency range is limited to avoid permanent damage to the targeted objects. Frequencies used most often range from 0.1 MHz to 25 MHz. Although Ultrasonic testing (UT) is capable of identifying surface defects, it is primarily used to detect and locate discontinuities that are below the surface, especially in metal parts. UT is useful for other types of inspection, including welds, wall thinning, and surface defects, as mentioned above [1] [7].

II. ULTRASOUND

Ultrasonic inspection uses sound as the source for testing the medium under consideration. This is the same kind of sound that creates the motion of our eardrums and allows us to hear. The vibrations used for Ultrasonic Testing (UT) are very much higher frequency than what we can hear. But just like any sound wave that moves through the air, the ultrasonic waves that are sent into metal will propagate through the solid medium. When these vibrations encounter interfaces between discontinuous materials (which represent defects in the materials and welds of pipes, for example) they will be reflected in predictable ways. UT is a commonly used method in industries for quality control purposes. It is useful for testing the integrity of metal parts, both before and after forming into pipes. The roll stock can be tested for invisible defects using straight beam ultrasonic testing, allowing the material to be categorized as acceptable, repairable, or scrap before it is incorporated into pipes [7] [17] [18]. Because air does not transmit ultrasound waves as well as solids or gels the difficulty of introducing the signals into metals is overcome by using water or grease as a conducting medium between the transducer and the material to be tested [13].

III. WAVES

Waves commonly used are:

Longitudinal Waves (LW): Another name for these waves is “compression waves”. LW is the type of sound wave that we hear, and that is used in manual UT for testing the front end and tail end of the pipe body, and in coil UT for testing the integrity of the plates before they are formed into pipe. The LW pushes the molecules of the tested material in the same direction as the movement of the wave.

Shear waves (SW): Shear waves, also known as transverse waves, propagate more slowly and at shorter wavelengths than LWs at equal frequencies. The particle motion is at right angles to the movement of the wave, as shown in Figure 2. SW is usually used for angle beam UT (for example, to detect discontinuities in both the inner diameter and outer diameter of the weld in pipes). As with LW, the SW velocity varies with the type of metal. Some example velocities and corresponding metal types are: Aluminum, roughly 3040 m/s; Steel, 347 Stainless, roughly 3100 m/s. When SWs reflect from an interface they sometimes become LWs [7] [20] [22] [23].

Rayleigh waves (RW): These waves, which penetrate the material only to the sub-surface distance of one wavelength (at any given frequency), are also called Surface waves. RW travels along the surface of the tested material at velocities equal to those of SWs. RWs are useful for detecting cracks that break the surface of the tested part. They are also useful for testing pieces with intricate rounded surface features. Any defect in zone α, would rest deeper than the wavelength (λ) of the test signal, and would likely not be detectable by RW [7] [20] [22].

Lamb waves (LMW): Lamb waves are vibrations that occur from the upper to the lower surface (up to several wavelengths in thickness) of the tested material, usually a plate (composites or metals), so they are also called Plate waves. They propagate not only through the full thickness of the tested material but are capable of propagating from a single point of excitation over significant distances within the material The velocity of LMWs is dependent on many factors, including density, plate thickness, and the elastic properties of the material being tested [7] [25].

IV. TRANSDUCERS

There are five general categories of ultrasonic transducers used in NDE: straight beam, angle beam, dual element, delay line and immersion transducers. Straight beam and angle beam transducers are used in pipe manufacturing NDE procedures. Usually, the standardized inspection codes will determine the type of transducer the manpower (operator) uses for a particular test. In the case where there are no specification or customer requirements, the operator will select a suitable transducer based on prior experience and knowledge [27]-[29]. Many studies investigated ways to reduce the manpower needed for inspection of pipes by using ultrasonic waves, and also ways to reduce the number of transducers required for an inspection protocol, in order to save capital expense.

Younho Cho et al. [32] carried out a feasibility study of using guided sonic signals for remote monitoring of stainless steel pipe. They report that their experimental approach, intended to allow them to optimize the guided wave mode resulted in the discovery that "Predicted modes could be successfully generated by controlling frequency, receiver angle and wavelength" [32]. By analyzing scattering patterns mode by mode, they were able to determine that "mode conversion characteristics are distinct depending on dispersive pattern of modes" [32].

V. STRAIGHT BEAM EVALUATION

The ultrasonic signal used for UT is not continuous. A brief pulse of ultrasound is emitted into the test material from a transducer; the signal travels through the test piece thickness and echoes from either the back wall of the piece, or from a discontinuity within the piece. The echoing signal is captured by the transducer only a few microseconds after being emitted. This gives the process the name pulse-echo [33].

The velocity of travel within the tested material must be known in order to calculate both the presence and the depth of the defect. In a flawless test piece, the distance down and back would each equal D, the full thickness of the metal. Thus, the transit time T represents the sonic waves propagating from probes S1 and S2 in both cases and the reflection from the back wall of the piece, so for the full thickness the total travel will be 2D. The factor (VL) is the velocity of LWs within the type of metal tested. If the signal finds a defect, the transit time TD would represent the sonic waves propagating from probe S3 in case 2 and the reflection from the interface of the defect, so the distance traveled will be 2DD where DD is the distance from the front surface to the interface with the defect. Thus, the velocity of LWs (VL) in this case is used to determine DD, and TD is the time of transit to and from the defect, as shown in Equation (2) [34].

VI. ANGLE BEAM EVALUATION

Straight beam ultrasonic techniques are best for locating defects in plate-type materials where defects are often parallel to the surface of the object, but they are ineffective for testing welds. The discontinuities in welds are usually at an angle to the surface of the sample under test. Beams approaching the weld interface at an angle are effective at detecting discontinuities within the welding bead. The angle beam transducer is used to generate the test signal in the majority of ultrasonic inspections. To assess discontinuities using angle beam examination, skip distance (SKD) is used to describe the sound path (SP) reflected from the back wall interface (1st leg) and going immediately to reflecting, where it is again reflected from the front wall (2nd leg). SKD is formed by the full SP (1st leg and 2nd leg), and is the distance from the point of excitation to the end of the second leg [17] [37]-[39].

VI. CONCLUSION

In recent years, low oil recovery efficiency, high energy consumption and high pollution have been key issues impeding the sustainable development of petroleum industry. As an emerging green technology, power ultrasound possesses great prospects in both upstream and downstream of the petroleum industry. In certain oil fields, power ultrasound is presently being used, successfully increasing oil production. ultrasound is effective in increasing oil production. In order to adapt to harsh underground conditions, improving the temperature and pressure resistance of transducers, cables and insulating materials is a necessary future pathway. It is usual practice to base an NDT research on the various materials used in order to estimate and evaluate the suitability of ultrasonic NDE for testing the materials involved. The next step is to develop the needed devices, then to investigate the problem of using the ultrasonic NDE technique to assess the structural objects. The angle beam is used to reveal discontinuities in the weld regions, with the limitation that the SKD cannot be increased unless the SP angle is increased. And that increased distance attenuates the sonic energy. The examples included in this article calculated the limitations of effective SD, SKD and SP using six reflection angles. The greater reach leads to reduced sensitivity because of the signal attenuation; operators must balance these factors when ultrasonic NDE is used. The general understanding is that 1 ½ SKD is the accepted limit of successful range for angle beam testing, all that according to the previous studies and technical websites. This requires continual attention by customer requirement and if there is no requirement, by the operator when assessing the integrity of pipes during manufacture. It is recommended that a second, powerful NDE technique capable of remote detection would be useful alongside ultrasonic testing in order to direct the placement of the probe.

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