Ultrasonic signal acquisition system for TOFD imaging

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Abstract. This article describes the development of an application to capture and process ultrasonic signals that will lead to the formation of flight time diffraction images, TOFD. In this way the theoretical basis of operation of this technique is presented establishing concepts such as type A and type D scanning. In addition, the ultrasonic waveforms that are used in this technique are presented. Application development is carried out through layered programming, which consists of three modules: information capture, information storage and finally data processing and graphing. However, the ultrasonic signal acquisition system designed and implemented in the laboratories of the Santo Tomás University of Bogotá D.C is presented as an alternate ultrasound system. For the verification of the system an exploration is carried out on a steel specimen that intentionally contains a hole inside it and the system determines its existence. In addition, a scan is performed on a steel sample with a weld bead and defects within the bead are verified.

1. Introduction
Exploration techniques through non-destructive tests on materials such as steel play an important role in the industry, since in metallurgy, for example, it is necessary to establish techniques to locate discontinuities in welded joints; it is there where the ultrasonic systems come into operation. From the acquisition of the ultrasonic signals, images can be formed that determine the structural health of the materials, in addition to locating defects and defining their type. These systems provide assistance to operators, since it is not necessary to destroy a material or structure to examine its composition. That is why within the research group of Modeling, Electronics and Monitoring (MEM), of the School of Electronic Engineering of the University Santo Tomas Bogotá D.C the research has been carried out for some years since the processing of ultrasonic signals, to locate discontinuities in welded joints.

2. TOFD technique
Flight time diffraction is an ultrasonic technique that allows you to examine a metallic material non-invasively. Using this technique, you can perform different types of solid material exploration, of which Type A and Type B scans are highlighted. [1][2][4]

2.1. Type A Scan
Type A scan is an ultrasonic signal that contains information about the variation in amplitude with respect to time; that is waveforms that are generated when an ultrasound wave interacts with an eventual discontinuity located within a metallic part. [3]
Examples of ultrasonic scanning signals type A are illustrated below considering a metallic part with and without discontinuity.

2.2. Type D Scan
An exploration D is a two-dimensional image constructed on the basis of a set of sweeps type A which are produced from the synchronous movement of a pair of transducers emitter-receiver along a certain direction of movement. Thus, for example, if said displacement is made with a spatial interval of one millimeter the generated sweeps A are stored each time the pair of transducers travels that distance. Subsequently, these sweeps are grouped to obtain a two-dimensional image scaled in shades of gray, in which each tone encodes amplitude values of type A signals. [3]
2.3. TOFD data interpretation

The signal that results in the receiving transducer is:

![Signal obtained in the receiver transducer using the TOFD technique](image)

**Figure 6.** Signal obtained in the receiver transducer using the TOFD technique.

Considering the origin of the time \( t=0 \) at the moment in which the excitation of the transducer transmitter \( T \) occurs, and \( t_l \) in which the lateral wave arrives at the receiver of the transducer \( R \). Furthermore, the delay time incorporated by the shoes must be considered; that is, \( 2t_o \), so that:

\[
2t_0 + t_1 = 12.2 \mu s
\]

However, \( t_l \) is the period of time taken by the lateral wave to travel the distance from the edge of the transmitter transducer \( T \) to the edge of the transducer \( R \), which is approximately:

\[
t_l = \frac{2S}{c} = \frac{45.42 \text{mm}}{5920 \text{ms}^{-1}} = 7.67 \mu s
\]

Therefore, the delay time entered by each shoe will be \( t_o=2.26 \mu s \). The arrival time interval used by the first diffracted wave must be:

\[
2t_o + t_2 = 12.2 \mu s + (t_2 - t_1)
\]

This last interval has a value of 0.3μs. This last interval has a value of 0.3μs; therefore \( t_2 \), the duration of the first diffracted wave will be 7.98μs. From these figures the depth of the defect can be determined; this is:

\[
d = \sqrt{\left(\frac{c}{2}\right)^2 t_2^2 - s^2}
\]

For the case at hand, a depth of 6.5mm is obtained. Repeating a similar analysis for the second diffracted wave is that:

\[
2t_o + t_3 = 12.2 \mu s + (t_2 - t_1) + (t_3 - t_2) = 12.2 \mu s + 0.3 \mu s + 0.7 \mu s
\]
From the above it obtains that \( t_3 = 8.68\mu s \), and therefore a distance travelled by the wave of 51.38mm. By Pythagoras we can determine the size of the defect; that is to say:

\[
(51.38/2)^2 - (45.42/2)^2 = (6.5 + h)^2
\]

From the above it is obtained that \( h = 5.5\)mm. Finally, we will find the transit time for the echo from the back wall by the following procedure:

\[
2t_0 + t_4 = 12.2\mu s + (t_2 - t_1) + (t_3 - t_2) + (t_4 - t_3) = 12.2\mu s + 0.3\mu s + 0.7\mu s + 0.28\mu s
\]

Given the equation (7) it is had for \( t_4 \) of 8.96\( \mu s \), a result that supplies the distance travelled by the mentioned echo with a value of 53.04mm, which, after being confronted with the theoretical value of 51.75mm throws an error of 2.5%.

3. Process

As mentioned earlier, research work focused on the detection of defects in welded joints, through non-invasive procedures, has been carried out in the electronic engineering faculty. The aforementioned process consisted of a DSP card, of foreign manufacture, that stimulated a transducer at the output port by means of a tip signal; well known in the field of END. Subsequently, through the input port, it received the signal from another transducer, and then stored it, processed using a series of algorithms developed by the group [1]. Because the card broke down, as if the investigation was interrupted, the group of researchers found it necessary to look for alternatives that would lead to solving the problem. This is how one of the members of the MEM group presented the problem to one of the authors of this article, who using a “button”, also developed by the group years ago managed to perform tests with the system and obtain images for processing. The “button” was developed by the seedbed of the MEM group, called Synapsis, which was in charge of another of its members.

![Figure 7. Tip type signal that drives the emitting transducer.](image)

The signal presented in figure (5) is called a lace because of the great amplitude it presents in such a short time, which for this case is approximately -240 V in an approximate time of 0.3us.

3.1. Computer connection interface with oscilloscope

A system was designed and implemented that enables the TBS 1052B reference oscilloscope as an analog-to-digital converter, whose schematic diagram is illustrated below.
Figure 8. Schematic diagram of the system.

When observing figure (8) the implemented system is divided into three modules:

- Capture information.
- Storage of information.
- Processing and graphing.

The software was implemented using the .NET framework. The VISA library provided by the Tektronix firm is used to capture the information. Subsequently, communication is established between the oscilloscope and a computer through a USB port. For the storage of the information two files are implemented in the hard disk of the computer, from a specified address. The first file is of the “.bmp” format, and the second is of the “.txt” format. In both files the information of the set of sweeps type A is contained, only that in the first one, it can be seen visually, while in the second one there is the data of the sweeps type A. For the graphic representation, an interface was developed in which the necessary controls are arranged to start and stop the captures of sweeps type A, and to store them as shown below.

Figure 9. Graphical user interface (GUI) of the application.

The application allows a possible user to use it in a Windows environment, in addition to having a plotter that allows you to visualize the type A sweeps, and the grouping of these as a two-dimensional image composed of shades of gray, also type D sweeps This image is achieved assigning a gray scale, so that the points of the captured signal where there is greater amplitude is the darkest tone, and the points of the signal where there is less amplitude, the tone is lighter. In addition, the user can set the number of captures he wishes to obtain, as well as the sampling time, he can also stop the acquisition.
3.2. Acquisition system
To perform these captures, it is necessary to install the ultrasonic transducers, the implemented push button, and the oscilloscope that performs the function of analog-digital converter. According to figure (10), the ultrasonic system has a button that is responsible for stimulating the transmitter. In addition, through the oscilloscope the signal provided by the transducer receiver is acquired, this information is sent to the computer via USB where the algorithms are provided for further processing.

![Alternative design of the ultrasound system.](image)

**Figure 10.** Ultrasonic information capture system.

4. Results
The exploration was carried out in a specimen that intentionally contains a hole in order to simulate a defect but this is not present in the whole specimen. For this capture the following enlarged image is obtained from the type D scan:

![Scan D into a specimen with a hole.](image)

**Figure 11.** Scan D into a specimen with a hole.

The previous figure shows a type D image where the darkest tones represent the largest signals that travel through the edge and bottom of the sample. Between these two waveforms are the signals that provide the information. However, the image does not show variation of the signal in a section, this is because the hole is not found in the whole specimen.

Tests were also carried out on specimens attached with a welding bead. The results showed the following:
In the same way as in the figure (11) a reference of greater amplitude (darker tone) is shown in the figure (12), and within this the information of the defects of the weld bead.

5. Conclusions
In this paper an ultrasonic signal acquisition system for TOFD imaging was presented. Based on the tests carried out, the social and industrial application of the system can be established, since by means of this the location of the defects present in metal structures can be determined without the need to destroy a piece or composition. The implemented system provides the necessary information of the captures made to the non-destructive tests, this plays an important role since if they want to export the data to another platform in which it is required to perform the image processing, for example to determine the type of defect in a welded joint, the thickness of the defect, its location etc, it can be done easily.

References
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