Processing of Large Amount of Experimental Data Collected During Laboratory Procedures

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Abstract

Processing of large experimental data files collected during laboratory procedures in the nondestructive evaluation (NDE) course is described in this paper. The main objective of this course is to introduce students to fundamentals of ultrasound measurements and to demonstrate the basic principles of ultrasound Nondestructive Evaluation (NDE) of materials by combining hands-on laboratory experience with lectures. In this course, students learn the physical principles and fundamentals of ultrasound material characterization. Students also learn industrial applications of NDE techniques and procedures and become familiar with detection and characterization of defects in materials, such as flaws and cracks. During the experiments, students collect extensive amount of data using UTWin software. Later, these data files are processed using Excel to evaluate ultrasound parameters of various materials, such as sound velocity, attenuation coefficients, and properties of piezoelectric transducers. The results of the experiments and conclusions are presented by the students in comprehensive laboratory reports. The process of comparing all individual files to calculate required parameters is very time consuming. This task can be simplified and automated using macros. The special Excel macros were developed to assist students with processing of the large data files. Evaluation of the collected data, the description of the final results, and data analysis are presented using figures, graphs, tables, or other convenient forms.

1. Introduction

The majority of courses of most of Engineering Technology programs are fully integrated with laboratory experience and extensive use of software. During the laboratory procedures, students collect large amount of data. These data are saved as Microsoft Excel files. Processing and evaluation of the collected experimental data, including required calculations, is very time-consuming. This routine task can be simplified and automated with the help of macros, which can better utilize students’ time and reduce errors. An Excel macro is a series of commands and functions that are stored in a Microsoft Visual Basic module that can be run periodically whenever a particular task needs to be performed [1-3]. Specifically, the use of Excel macros as an assisting tool for processing of the data files collected during laboratory procedures in ultrasound nondestructive evaluation (NDE) course is presented in this paper. During the first part of this course, students learn fundamentals of ultrasound NDE techniques. Specifically, they learn measurement procedures of sound velocity of various materials, directivity pattern of piezoelectric transducers, and attenuation coefficients [4]. During the experiments, students collect extensive amount of data using commercial water tank-based system. Later, these data saved as Excel files and processed to evaluate and compare parameters of sinusoidal pulses. For example, for measuring sound velocity, the time difference between positive or negative peaks of
two consecutive pulses has to be carefully evaluated for proper calculations. In another experiment, for evaluation of attenuation coefficients, peak to peak amplitudes of sinusoidal pulses for all of the collected data files should be compared. Altogether, hundreds of files need to be collected and evaluated for computation of various parameters.

For all experiments, the collected data files are stored in Excel format within different folders on a PC. Each folder has specific name according to a particular experiment and can be easily distinguished from folders for other experiments. All Excel data files contain amplitude vs time information for the sinusoidal ultrasound signal relevant to the experiment being performed (Figure 1). In the absence of macros, students would be required to individually open each data file and compute the parameter of interest, such as peak to peak amplitude or times for positive peak and negative peak of the sinusoidal pulse, respectively. The students should spend significant amount of time going through up to several hundred individual data files in order to obtain the parameter of interest. Once the parameter of interest has been obtained, students use those parameters for calculations and analysis.

Excel macros have been developed and provided to the students as a tool to assist with the data analysis and calculations. Utilizing the developed macros, students are only required to select any one file within a folder and computations of interest are automatically applied to all of the Excel files within that particular folder, allowing for calculations of hundreds of files within a minute. After common computations are applied to all Excel data files within a folder, students can use the macro to list all the computed parameters from all the data files together in the same subfolder. Once all the computed parameters have been listed together in one subfolder, they again can be utilized for further evaluation and analysis.

2. Selected Laboratory Procedures

For illustration of the laboratory experiments that require collection of large number of the collected data files, two laboratory procedures are described below.

2.1. Measurements of the sound velocity in water

Most applications of underwater acoustics, nondestructive evaluation of materials, and biomedical ultrasound rely on accurate measurements of the sound velocity in water and other materials. The basic principle of sound velocity determination is to measure the time between transmitted and received ultrasound signals (time-of-flight) [5, 6]. In these experiments, the measurement of the transducer displacement is more convenient and accurate than the measurement of the transmitter/receiver or transducer/reflector distance. Such a technique allows one to eliminate additional artifacts caused by the time delays from the transducers and associated electronics. During this laboratory, the two sets of measurements are carried out using:

a. One transducer, operating as a transmitter/receiver, and the reflector
b. Two transducers, where one of them is used as a transmitter, and the other one is used as a receiver (In this experiment, the reflector is replaced by the second transducer)

Initially, transducers are installed at about 200 mm apart and aligned. The received signal is collected and saved as an Excel file in the computer. Then, the distance between transducers is increased by moving one of the transducers with 50 mm increments to three different positions using UTwin Software. At each of these positions, the data is again collected and saved in the computer. The results obtained from these positions are later averaged. By measuring the time interval between peak values (positive or negative) of the received pulses and knowing the displacement of one of the transducers, one can estimate the sound velocity in water, as $c = \frac{x}{\Delta t}$, where $x$ is the displacement of the transducer and $\Delta t$ is the time interval between two consecutive received pulses (Figure 1). If one of the transducers is replaced with the reflector, then the sound velocity can be calculated as $c = \frac{2x}{\Delta t}$, since the ultrasound wave propagates in both directions - from the transducer, which acts as a transmitter, to the reflector and then back to the transducer, which acts as a receiver. Collected data are saved as Excel files for future processing.

![Figure 1. Sample data plot for 2.25 MHz transducer.](image)

### 2.2. Directivity Pattern of Piezoelectric Transducers

In this laboratory session, the directivity pattern is determined analytically and measured experimentally [7]. During the experiment, a projector and a hydrophone (two transducers) are separated by the minimum acceptable distance, $x$, to minimize interference from reflections. The standard criteria for uniform circular pistons are

$$x \geq \frac{d^2}{4\lambda}$$  \hspace{1cm} (4)

where $\lambda = \frac{c}{f}$ is the wavelength, $f$ is the resonant frequency of the transducer, and $d$ is the diameter of a circular transducer. Initially, both transducers are aligned in $x$, $y$, $z$, and $\theta$ directions. The alignment is based on the recording of the maximum amplitude of the received
signal at the axial direction. Directivity pattern measurements are carried out for all three pairs of transducers with the resonant frequencies of 2.25 MHz, 3.5 MHz, and 5 MHz. For each pair of the transducers, the first transducer is fixed and the other is rotated from $0^\circ$ to $10^\circ$ in $0.1^\circ$ increments. For each angle, the peak-to-peak voltage of the received signal is recorded, and the data are saved in the computer as Excel files for future processing using Microsoft Excel.

It is clear from the experiments described above that hundreds of files must be collected and processed for computation of required parameters. Macros allow for simplification and automation of the computational process.

3. Macros

3.1. Macro for Computations

All of the collected data files represent the ultrasound sinusoidal waveform information with column A containing time in microseconds and column B containing amplitude values (Figure 2). All experimental data files for a particular experiment are saved in one folder. All experimental calculations and analysis of data require the use of either peak-to-peak amplitude values or time values for the positive/negative peak of the sinusoidal signal. A macro for calculation of directivity patterns or attenuation coefficients evaluates peak-to-peak amplitude of the collected sinusoidal signals. A macro for calculation of sound velocity of different materials evaluates times for positive or negative peak of two consecutive sinusoidal signals. The macro is recorded using the “Record Macro” feature of Microsoft Excel. A Visual Basic for Applications (VBA) code uses the previously recorded macro and applies it to all Excel files within a folder.

![Figure 2](image)

Figure 2. Portion of the Excel spreadsheet showing 19 of the 438 Amplitude vs Time (μsec) data points (left). The sinusoidal pulse waveform obtained using all of the 438 data points in Columns A and B (right).
When the particular Excel macro file is opened, the window (Figure 3) opens up. A command button with the heading “Locate Folder” allows students to select the folder, to which the macro is applied.

**Figure 3.** Folder location for a particular macro.

Once the macro completed required computations within the selected folder, the window pops up (Figure 4) indicating that macro finished computations. It may take for the macro less than a minute to complete all computations for up to 100 files within a folder.

**Figure 4.** Window indicating the end of macro computations.

Once “OK” of the window shown in Figure 3 is clicked, the window shown in Figure 2 is activated again allowing students to either browse for another folder or to exit the macro.

After the macro has finished computations of all files within a folder, the computed values for each individual file are presented in the following format (Figure 5):
### Figure 5.
The computed peak to peak amplitude and the time for positive and negative peaks for one of the experimental data files.

#### 3.2. Macro for Retrieving Computed Values

Once peak to peak amplitude values and the time for positive and negative peaks have been computed for all files within a folder, students can activate another macro to retrieve the computed values from those files and have them listed together in one datasheet to simplify analysis of the data. As was previously mentioned, some experiments require only peak-to-peak amplitude values, but other experiments require the data about times for positive peak and negative peak for further calculations. The second macro allows students to select a particular experiment for which they wish to retrieve the data (Figure 6). If the student selects “Measurement of Sound Velocity in Water and Other Materials”, then times for positive peak and negative peak will be listed together. However, if the student selects “Directivity Pattern” or “Attenuation Coefficient” then peak-to-peak amplitude values will be listed together. In addition, the data for directivity pattern of piezoelectric transducers should be normalized relative to the maximum value. This normalized maximum value is equal to 1 for an axial direction. During the measurement of directivity pattern of transducers, students collect data as peak-to-peak voltages of the received signals for different angles. These actual voltages should be normalized relative the maximum value obtained during the experiment. The macro also computes normalized peak-to-peak amplitude values thereby further saving time for data processing and analysis. So that, the first macro computes peak-to-peak amplitude values and times for positive peak and negative peak of the sinusoidal waveform for all the files within a folder. The computed values are placed in specific cells of the spreadsheet for all the files in a particular folder. The second macro goes through each of the individual files within that folder, retrieves values from those specific cells, and lists them together in the macro spreadsheet.

The required parameters for a particular experiment can be retrieved by clicking on the corresponding “Locate Folder” command button and selecting the folder that holds the data files for that experiment. Once the folder has been selected, Columns B, C and/or D will show the parameters that were retrieved from all Excel files and were saved inside the selected folder. If the macro is executed again for another folder, columns B, C and/or D will be over-written by the data retrieved from the selected folder. To avoid the confusion that overwritten data may cause, “Clean Spreadsheet” command button is provided to clean the spreadsheet before running the macro on another folder.
Figure 6. The macro for selecting a particular experiment.

Once the macro has finished retrieving computed values from all the Excel files within a folder, they are displayed in the spreadsheet, such as presented in Figure 7. In Figure 7 specifically presented below, the macro was used to retrieve time values for positive peak and negative peak for computation of the sound velocity in water. Listing all the data together in this way saves significant time for calculations as students are no longer required to individually open each file to retrieve the necessary parameter.
Figure 7. Retrieved time values for positive peak and negative peak from all the Excel files within a folder. Column B shows file name, column C shows time for positive peak in μsec, and column D shows time for negative peak in μsec.

4. Computations of Experimental Parameters

After the macros were used to compute required parameters of the waveform and all the data were retrieved, students can proceed with the calculations of the required parameters for a particular experiment. An Excel spreadsheet with all the necessary formulas was created for calculations (Figure 8). The cells with formulas are locked so the formulas do not get erased by a mistake. However, the formulas are visible when a particular cell is clicked so students can verify how the calculations were performed.

<table>
<thead>
<tr>
<th>Frequency in MHz</th>
<th>t and Δt in μsec (Through Transmission: Two Transducers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>50 mm</td>
</tr>
<tr>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8. Excel spreadsheet for calculations.

Students are not required to convert microseconds to seconds. They are only required to copy the values obtained through the macro (Figure 7) and paste them in the corresponding cell of the
spreadsheet (Figure 8). The double arrows show the cells where the parameters obtained through the macro will be pasted. Δt values will be calculated automatically.

In addition to calculations of the required parameters, the errors of the experimental results can be evaluated using the Excel spreadsheet presented in Figure 9. Once calculated values of the sound velocity for each experiment have been entered in the required cells, students enter the reference values of the sound velocity in water in the designated cells. Percentage errors will automatically be calculated for values of sound velocity in water obtained by the students experimentally.

<table>
<thead>
<tr>
<th>Frequency in MHz</th>
<th>Ref. Velocity m/sec</th>
<th>Velocity m/s 50 mm</th>
<th>% Error 50 mm</th>
<th>Velocity m/s 100 mm</th>
<th>% Error 100 mm</th>
<th>Velocity m/s 150 mm</th>
<th>% Error 150 mm</th>
<th>Average Velocity m/sec</th>
<th>Average % Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td>5</td>
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</tbody>
</table>

**Figure 9.** Spreadsheet for calculations of errors of the experimental data.

5. **Summary**

The Excel macros as an assisting tool for processing of the large data files collected during laboratory procedures in the nondestructive evaluation (NDE) course is described in this paper. In this course, students learn fundamentals of Ultrasound NDE and industrial NDE procedures. Specifically, they learn measurement procedures of sound velocity in different materials, directivity pattern of piezoelectric transducers, and attenuation coefficient, among others. During the experiments, students collect extensive amount of data using special UTWin software. Later, these data are processed using Excel to evaluate and compare parameters of sinusoidal pulses, such as time for positive or negative peak and peak-to-peak amplitude voltage for all of the collected data files. The results of the experiments and conclusions are presented by the students in comprehensive laboratory reports. The process of comparing of all individual files to calculate required parameters is very time-consuming. This task can be simplified and automated using macros. Two Excel macros were developed by the graduate teaching assistant and provided to students to assist with the processing of data stored in the form of Excel files. The first macro evaluates pulse parameters, such as times for positive peak and negative peak, and peak-to-peak amplitude voltage for all of the Excel files that are stored inside a particular folder. The second macro combines all of the evaluated parameters together in one Excel file. Utilizing this approach to teaching laboratory-based courses allows for reduction of the time-consuming procedures during processing of experimental data, data analysis, and preparing comprehensive laboratory reports.
References