Quality Control Education - A University Course in Acoustic Emission

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Abstract

The four-credit (forty hours) Acoustic Emission course was developed for Drexel University's engineering technology (ET) and engineering students. The course presents principles of Acoustic Emission (AE) Nondestructive Evaluation of Materials (NDE), combining hands-on laboratory experience with lectures. The students learn the physical principles of acoustic emission generation, propagation and detection in engineering materials and structures. This includes principles of stress and strain and the underlying science of material deformation, crack growth and failure. Students also learn how these principles are utilized to build technical applications of acoustic emission considered as an NDE method. Practical applications in various industries are described. During laboratory sessions, students are introduced to tools, methodologies, and techniques used by NDE specialists in real-world applications. Specifically, the students observe acoustic emission in metals, composite materials and plastics; study acoustic wave propagation and attenuation; learn how to check a set of sensors for consistent sensitivity; set up an acoustic emission system for automatic source location; and engage in structural test data analysis. A laboratory report, clearly describing collected data, results, conclusions, and comments is required after completion of each laboratory session.

1. Introduction

The need for a large number of practical engineers with a background in advanced and emerging technologies over the next decade has been clearly identified[1-5]. Engineering education is changing, with its focus shifting from the traditional theory-based curriculum to team-based learning, problem solving with open-ended solutions, hands-on projects, and team-oriented communications[6-9]. Addressing the need for skilled technology workers is a required competitive and survival strategy for most manufacturers[10, 11].

Drexel University is the leading institution of higher education in the Delaware Valley and Greater Philadelphia region that offers a bachelor of science (B.S.) degree in engineering technology accredited by ABET. The ET program was initiated as a response to job- and education-related issues expressed by government, academic institutions, and industries across the nation. The ET program's content provides an integrated educational experience directed toward developing the ability to apply fundamental knowledge to the solution of practical problems in engineering technology fields. The majority of the ET courses at Drexel are fully integrated with training and laboratory experience and extensive use of software and industrial case studies[12].

A new generation of industrial engineers, manufacturing engineers, and engineering technologists must be educated and trained in various quality control-related techniques, methodologies, and corresponding equipment. Consequently, the role of NDE in assuring public safety is greatly increasing. The New York Times reports that more than a quarter of the nation's bridges are structurally deficient or functionally obsolete and leaky pipes lose an estimated seven billion gallons of clean drinking water every day (Michael Cooper. U.S. Infrastructure Is In Dire Straits. *New York Times*, January 28, 2009, p. A16). Similar issues exist in other areas, such as maintenance and diagnostic techniques for nuclear power plants, petrochemical and aerospace

industries. Filling industry's need for NDE personnel in the future constitutes a significant challenge to America's colleges and universities. To meet these demands, there must be a renewed emphasis on NDE educational efforts, particularly within the curricula for engineering and engineering technology students. The integration of NDE technology with related engineering studies is a significant step in that direction[13].

Two courses, namely Ultrasound NDE, EET 333 and Acoustic Emission (AE), EET 335, have been developed and offered to engineering technology and engineering students. The AE method is used for inspection of refineries, pipelines, power generation plants, aircrafts, offshore oil platforms, and paper mills. Structures frequently tested also include bridges, tunnels, towers, cranes, and heavy industrial equipment. The AE method is used for detection of discontinuities as they occurred. The course will introduce students to state-of-the-art AE techniques and equipment.

EET 333 was developed, with support from the NSF, as a four-credit, forty-hour course to fulfill Levels I & II NDE in theory and training requirements, according to ASNT (American Society for Nondestructive Testing) Recommended Practice SNT-TC-1A[14-16]. This course was offered in two modes: the traditional face-to-face classroom mode for students on Drexel's campus, and a real-time, Internet-based mode for those at remote locations. The EET 335 course was initially developed as a three-credit course and offered as a special topic course for two consecutive years. The course has been modified to a four-credit (forty-hour) course to satisfy the requirements of the ASNT. The experience gained during the development of EET 333 course will be utilized for developing Internet-based remote control of real-time laboratory procedures.

2. Acoustic Emission Course

2.1. Course Objectives and Student Learning Outcomes (SLOs)

The course presents principles of Acoustic Emission Nondestructive Evaluation of Materials combining hands-on laboratory experience with lectures. The students learn the physical principles of acoustic emission generation, propagation and detection in engineering materials and structures. This includes principles of stress and strain and the underlying materials science of material deformation, crack growth and failure. Students also learn how these principles are utilized to build technical applications of acoustic emission considered as an NDE method. Practical applications in various industries are described.

Course objectives:

- Introduce students to concepts of materials science, stress and strain, acoustic waves and electronics technology that can be valuable in many kinds of engineering work. These fields of knowledge are brought together in acoustic emission technology used for enhancing safety and prolonging the life of industrial plant and infrastructure. The course will combine lectures with hands-on laboratory experience.
- Introduce students to engineering measurements of material deformation and the acoustic emission phenomenon during the laboratory procedures.
- Develop skills in observing and measuring, recording and reporting through the performance of the typical activities of acoustic emission test technology. Specifically, students will observe acoustic emission in metals, composite materials and plastics; study

acoustic wave propagation and attenuation; learn how to check a set of sensors for consistent sensitivity; set up an acoustic emission system for automatic source location; and engage in structural test data analysis. The work in the laboratory will enhance the fundamentals taught in the classroom sessions.

- Introduce students to techniques for assessing experimental error and reliability and processing experimental data.
- Improve students' communication skills through the laboratory reports and presentations.

Student Learning Outcomes:
Upon completion of the course the students will:

1. Understand fundamentals and principles of Acoustic Emission (AE):

- Become familiar with basic acoustic emission instrumentation.
- Be skilled in the use of the pencil lead break technique for sensor checking, AE wave propagation and attenuation measurements, test setup etc.
- Be able to describe the nature of the AE process, its use in NDT and its distinctive features as an NDT method.
- Be able to calculate stress and strain in simple situations and explain the relationship between stress, strain and elastic and plastic deformation.
- Recognize the Kaiser and Felicity effects and describe their relationship to material stability and flaw severity.

2. Gain hands-on experience with Acoustic Emission equipment and accessories:

- Appreciate the influence of AE instrument settings on the acquired data.
  - Threshold
  - Timing parameters
  - Frequency filters
  - Waveform recording settings
- Be able to set up an AE instrument to perform source location indicating the position of a pencil lead break event correctly.
- Be able to recognize sensor resonant frequencies in the observed AE signal and to relate these to the measured frequency spectrum.

3. Become familiar with the advantages and limitations of AE procedures and techniques:

- Recognize the commonly used signal features and their role in describing AE activity and intensity and performing interpretation and evaluation.
- Be able to set up AE data displays (histograms, scatter plots etc.) and explain what they are showing.
- Have some experience in analyzing multi-channel E data from full-scale structural tests.

4. Improve professional communication skills through laboratory reports and presentations.

The AE course can be assessed based on the ABET requirements. The alignment of SLOs and ABET outcomes is presented in Table 1.

Table 1. Student Learning Outcomes (SLOs) Aligned with ABET Student Outcomes (a-k)

	ABET Student Outcomes[1]	a	b	c	d	e	f	g	h	i	j	k
SLO 1:	Understand fundamentals and principles of Acoustic Emission (AE)		X			X						
SLO 2:	Gain hands-on experience with Acoustic Emission equipment and accessories	X				X						
SLO 3:	Become familiar with the advantages and limitations of AE procedures and techniques			X		X						
SLO 4:	Improve professional communication skills through laboratory reports and presentations					X		X				X

[1]Upon successful completion of this program, students will attain the following outcomes:

a. an ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities;
b. an ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies;
c. an ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes;
d. an ability to design systems, components, or processes for broadly-defined engineering technology problems appropriate to program educational objectives;
e. an ability to function effectively as a member or leader on a technical team;
f. an ability to identify, analyze, and solve broadly-defined engineering technology problems;
g. an ability to apply written, oral, and graphical communication in both technical and non- technical environments; and an ability to identify and use appropriate technical literature;
h. an understanding of the need for and an ability to engage in self-directed continuing professional development;
i. an understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity;
j. a knowledge of the impact of engineering technology solutions in a societal and global context;
k. a commitment to quality, timeliness, and continuous improvement.

2.2. Topics Covered in the AE Course

The AE course is a blend of lectures and laboratory projects. All the students work at the same time on the same lab in pairs with each pair having its own equipment. In the course of adapting the technical material to fit this logistical plan, some of the inspector-course labs underwent significant change and several entirely new labs were created. During the laboratory procedures, the instructor directly leads the activities.

A versatile set of AE equipment, parts, and components was purchased and centered around six USB AE Nodes which can be deployed as single-channel systems at six separate workstations, or alternatively can be connected together for multi-channel projects. These Nodes detect and measure AE signals from associated sensors, and deliver the results via USB connections to computers running AEWin software. Thus during a typical lab, the data taken by each pair of students is stored on the computers in the NDE lab. The topics covered in this course during lectures and laboratory procedures are presented below in Table 2.

Table 2. Topics covered in the AE course.

Week	Date	Instructor	Topic(s)	Location
1	TBA	TBA	Introduction: NDT and the Acoustic Emission Method Demonstration: AE from Plexiglas Microstructure and AE Sources in Unflawed Materials	TBA
2	TBA	TBA	Microstructure and AE Sources in Unflawed Materials Lab: AE from Brass Tensile Specimen Load, Stress, Strain and Materials AE Source Physics: Energy, Motion and Signal Amplitude	TBA
3	TBA	TBA	AE Wave Propagation AE Sensors; Pencil Lead Break Technique Lab: Wave Propagation Measurements (Pipe) Lab: Lucite Rod for Sensor Check and Wave Propagation	TBA
4	TBA	TBA	Crack Growth in Metals and Associated AE AE, Time and Load Lab: Stress Corrosion Cracking in Plexiglas	TBA
5	TBA		Mid Term (Written Exam)	TBA
6	TBA	TBA	Signal Conditioning and Detection Measured Features and their Uses Introduction to Frequency Analysis Lab: AE Signal Measurement (Effect of Settings)	TBA
7	TBA	TBA	AE from Non-Metals and Composite Materials Lab: AE from Fiberglass Ring Lab: Wave Propagation and Attenuation in Composites	TBA
8	TBA	TBA	AE Source Location Techniques AE from Crack Growth in 7075-T6 Al (with source location) Planar Source Location Setup	TBA
9	TBA	TBA	Noise Countermeasures: Interpretation and Evaluation Test Procedures, Applications, Hands On Data Analysis (1)	TBA
10	TBA	TBA	Test Procedures, Applications, Hands On Data Analysis (2)	TBA
11	TBA	TBA	Presentations (each lab reviewed by one or two students)	TBA

Selected laboratory experiments are described in the following section.

3. Selected Laboratory Experiments

3.1. Lucite Rod Pencil Lead Breaks

In this experiment, proper technique is developed for producing consistent Pencil Lead Breaks (PLBs) on a Lucite rod (Figure 1). Pencil Lead Breaks technique is an industry-standard method for producing consistent acoustic events of reliable magnitude[17]. Done properly, this method produces quite consistent results, and is a reliable way of testing sensors, when performed on a Lucite rod[18]. PLBs are performed 4" from the end of the rod, on the marked lines visible in Figure 1.

The initial setup of the apparatus involves placing an acoustic transducer at one end of a Lucite rod. Normally, tape, a clamp, or another mechanism would be used to affix the transducer to the rod. However, since the experiment will be carried out under benign, controlled conditions, it is sufficient to simply use vacuum grease to both provide acoustic coupling to the Lucite rod, as well as to hold the transducer in place (Figures 2 and 3.)

Figure 1. The Lucite rod is secured to the table.

Figure 2. A generous amount of vacuum grease is applied to the transducer.

Figure 3. The sensor is pressed in place on the end of the Lucite rod.

Once the Acoustic Emissions software has been configured to record acoustic events, students commence practicing Pencil Lead Breaks (PLBs) on the Lucite rod. PLBs are performed by extending 2-3mm of pencil lead from the tip of a mechanical pencil, and holding the pencil at a 30-degree angle to the Lucite rod[17]. Pressure is applied downwards until the lead breaks, taking care not to allow the metal tip of the pencil to contact the Lucite. (Contact between the metal and the Lucite would cause a secondary acoustic event.) This technique is demonstrated in Figure 4.

Figure 4. Pencil Lead Break technique.

The goal of this lab exercise is to introduce students to the PLBs technique and to achieve consistency of the results for repeatable, uniform acoustic events. To measure consistency, the Line Display window of the AEWin software is shown. Students note the measured peak acoustic amplitude for their PLBs. Ideally, PLB amplitudes should be within a few dB of each other. The Line Display window is shown in Figure 5.

ID	DDD	HH:MM:SS.mmmuuun	PARA1	CH	RISE	COUN	ENER	DURATION	AMP
128	0	00:00:00.0000000	Acquisition Running						
ID	DDD	HH:MM:SS.mmmuuun	PARA1	CH	RISE	COUN	ENER	DURATION	AMP
1	0	00:00:04.4382190	0.1465	1	30	6	2	191	52
1	0	00:00:04.6581363	0.1465	1	61	59	23	857	60
1	0	00:00:04.6727017	0.1465	1	463	14	7	622	51

Figure 5. Line Display results, showing amplitude in the rightmost column.
(Note that such variation in amplitude would indicate that more PLB practice is needed.)

3.2. Acoustic Emissions from a Fiberglass Ring

When subjected to physical stress, such as compression, materials produce characteristic "burst" and "continuous" acoustic emissions that can be analyzed to determine various properties of the material under test[19]. In this experiment, fiberglass ring specimens (both unflawed as well as notched) are subjected to compression while continuous and burst-type acoustic emissions from the specimens are monitored.

By subjecting fiberglass ring samples to a controlled amount of compression (Figure 6) while recording continuous and burst-type acoustic emissions, the differences in emission between unflawed and cut (damaged) specimens can be seen. A custom tensioning jig has been made for this purpose. By tightening the thumbscrews at uniform intervals, students can accurately apply increasing loads to the sample. The plastic washers and duct tape serve to mitigate metal-on-metal noise emission.

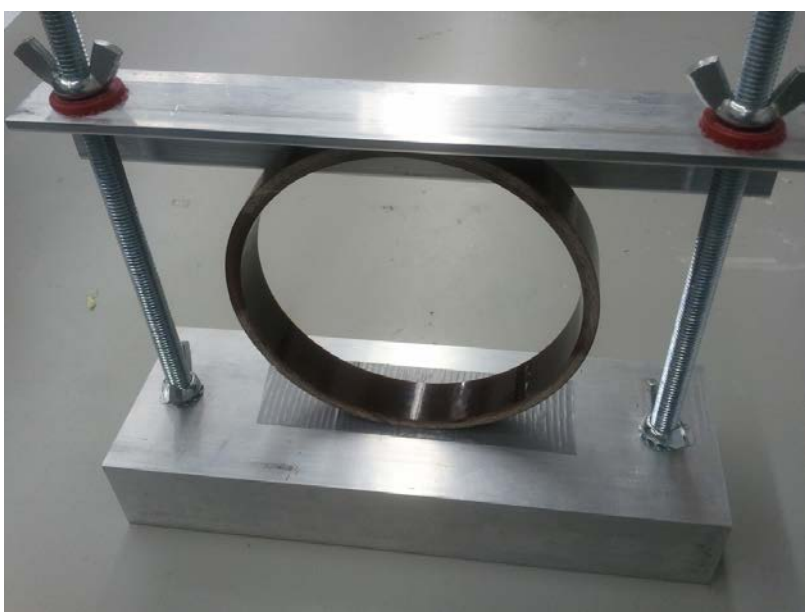

Figure 6. The fiberglass ring in the tensioning jig.

In order to capture and analyze the acoustic emissions from the stressed sample, an acoustic transducer is attached to the ring at the 45-degree point on one side (Figure 7).

A custom-designed timing device (Figure 7) measures uniform 20-second intervals. When the timer indicates each time period, students tighten each thumbscrew by one half turn. Burst transmissions are thereby predominantly produced in 20-second intervals, corresponding to the periodic onset of increased stress[20], with increasing amounts of continuous emission between these times. (Continuous emissions are seen to increase at higher stress levels.)

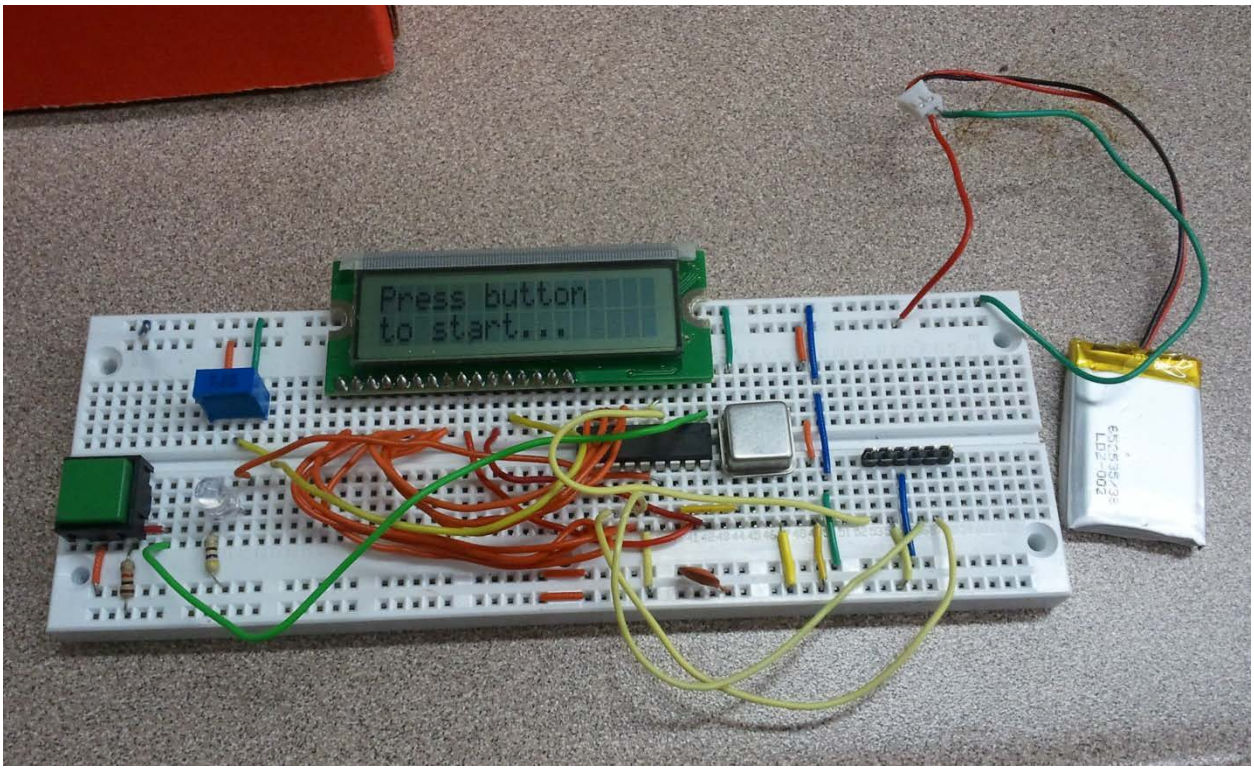

Figure 7. A prototype of a precise twenty-second timer, built for this experiment.

The experiment is conducted with both unflawed and cut specimens. For the cut specimens, a notch with a depth of approximately 2-3 mm is cut into the side of the specimen nearest the transducer. The inclusion of this flaw significantly increases the amount of both continuous and burst emissions. By comparing the emissions made by the unflawed and notched specimens, students can distinguish the effect of sample defects on acoustic emission under load.

3.3. Source Location on a Metal Plate

Acoustic Emission techniques are used to locate the source of acoustic emission-generating events (such as pencil lead breaks) on a planar sheet of metal. Since sound propagates at a known velocity in a given medium (steel, in this case), acoustic sensors can be placed at known locations and the differences in event arrival times can be used to calculate the position of the event. A 3D version of these calculations, along with other corrections, is also used by GPS systems to determine latitude, longitude, and altitude[21].

A 4’ x 3’ sheet of metal is used for the experiment. Four AE sensors are placed near the corners of the metal sheet (Figures 8 and 9.) Each sensor is connected to the AE node, which in turn is

connected to the computer. Also, the four nodes are connected together by a synchronization cable. This allows precise determination of the difference in timing between event detections at the four sensors. Since surface wave propagates at approximately 120,000 in/sec in a steel plate, a difference in time of one microsecond between detection by sensors A and B would mean that an event occurred 0.12 inches closer to Sensor A than Sensor B. This difference, when plotted, would produce a hyperbola. Combining this with time differences from other sensor pairs (B-C, C-D, A-C, A-D, and B-D) enables accurate calculation of the position of the event in 2D. The experiment can be controlled locally in NDE laboratory or remotely through the use of VNC, allowing students at remote locations to operate the Acoustic Emission procedure. The Acoustic Emissions processing is handled by the AEWin software.

Figure 8. The four acoustic sensors are placed near the corners, 1” from each side.

Figure 9. Each acoustic sensor is held in place by a C-clamp.

Using the “AE Sensor Placement” dialog box in the AEWin software, the position of the four acoustic sensors is entered (Figure 10.) The lower left corner of the metal sheet is defined to be

the origin (that is, X,Y = 0,0). X coordinates, in inches, are positive to the right; Y coordinates, in inches, are positive going up/forward.
Since the plate measures 48 by 36 inches, and the sensors are placed in the corners, one inch from each edge, their locations are as follows:
(sensors are numbered counterclockwise from upper right):

Sensor 1: X=47; Y=35	(upper right corner)
Sensor 2: X=1; Y=35	(upper left corner)
Sensor 3: X=1; Y=1	(lower left corner, near the origin)
Sensor 4: X=47; Y=1	(lower right corner)

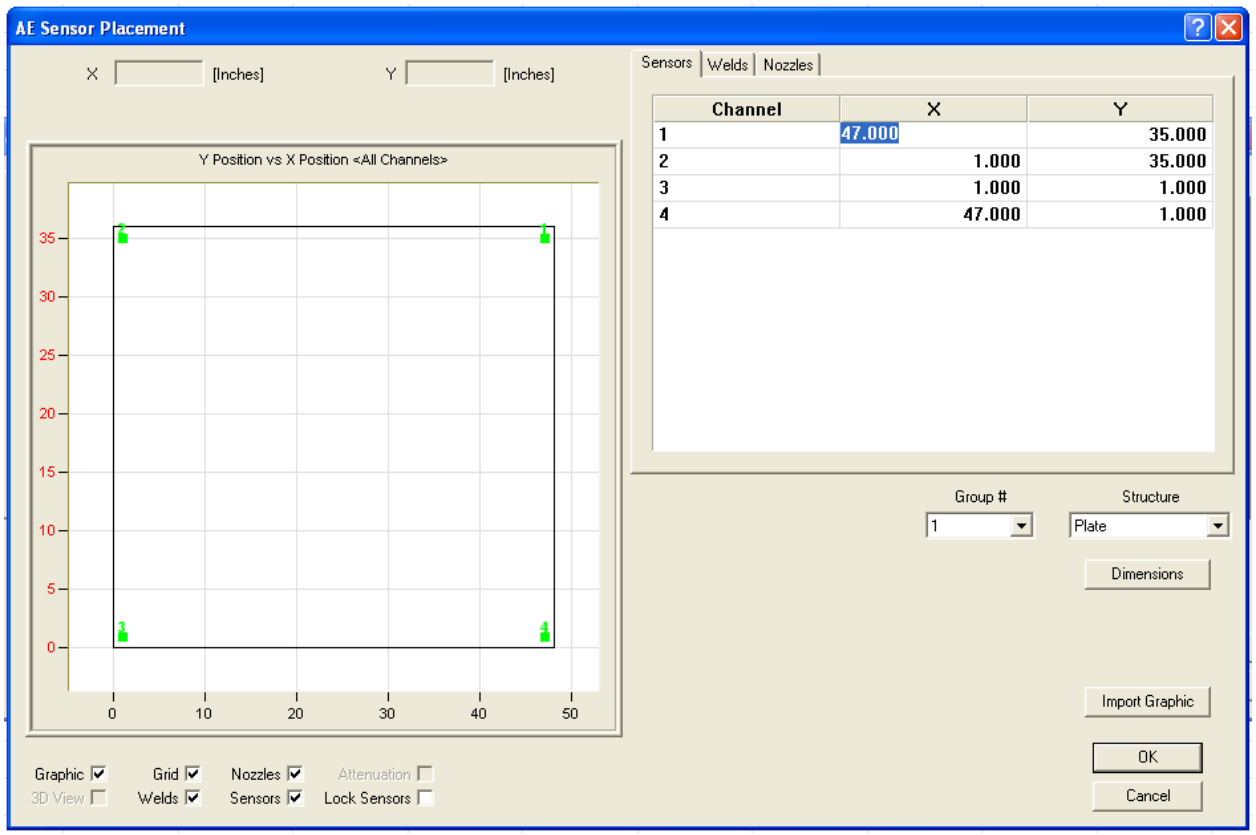

Figure 10. Entering the physical coordinates for the sensors.

Once the sensor positions have been configured and the parameters chosen, acquisition is started. Standard Pencil Lead Breaks (PLBs) are performed at various known locations on the sheet, and the calculated locations of the acoustic event (as calculated by the AEWin software) are shown on the screen (Figure 11.) Students compare these locations to the actual measured locations of the PLB events.

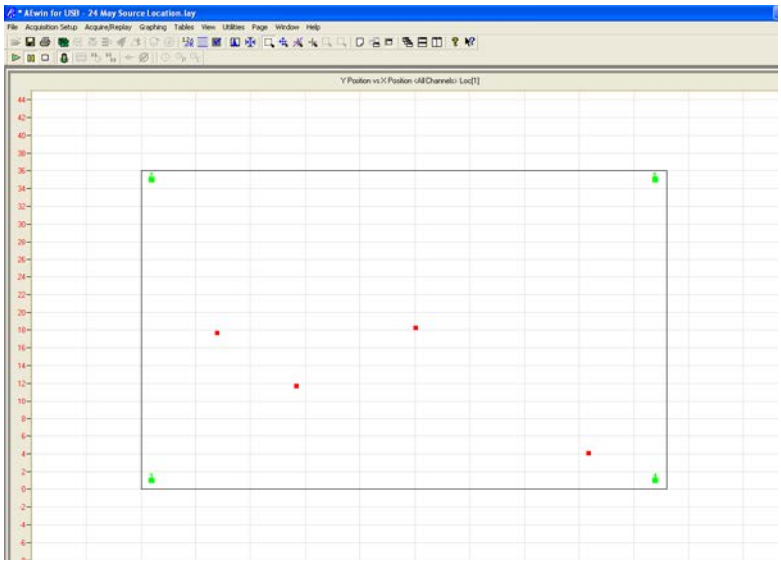

Figure 11. The positions of several pencil lead breaks, shown on the graphical view.

In addition to locating events in 2D, the AEWin software can be used to show the waveforms from individual events. Students select one PLB event as shown on the 2D graphical view, and view the waveforms from that event as received by the various sensors. Since the triggering thresholds and event trigger times are shown on the display, students can see the time differences between the sound arrival events at various sensors. For example, an event might occur closest to sensor 3, and might be received by sensors 3, 2, and 4, in that order (Figure 12).

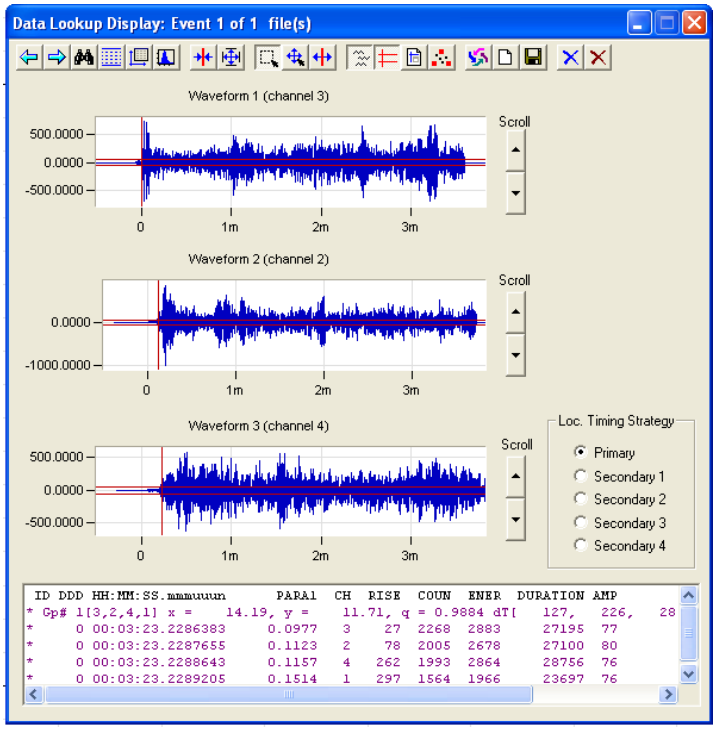

Figure 12. Waveforms from a single event, as received at sensors 3, 2, and 4

4. Summary

An organized program of study in NDE at the undergraduate and graduate levels using both face-to-face and real-time remote Internet-based instruction during lectures and laboratory sessions is under development. Currently, two courses have been developed and offered to engineering and engineering technology students of Drexel University. The Ultrasound NDE (EET 333) course is a required course for engineering technology students. The most recently developed NDE four-credit course, namely Acoustic Emission (EET 335), was approved by the Faculty Senate as a technical elective. The acoustic emission method is used for inspection of refineries, pipelines, power generation plants, aircrafts, offshore oil platforms, and paper mills. Structures frequently tested also include bridges, tunnels, towers, cranes, and heavy industrial equipment. The AE method is used for detection of discontinuities as they occur. Both courses consist of two parts. The first part emphasizes the foundations of a particular NDE method. The second part has a focus on specific NDE applications and techniques. These techniques are studied through experiments that closely simulate industry-relevant processes or scenarios in a pilot-scale manufacturing and testing processes. Both courses were developed according to the requirements of the American Society for Nondestructive Testing in collaboration with industrial companies that participated in the development and implementation phases of the project. The developed acoustic emission course can be implemented for education and training of students of other universities, community colleges, and employees of companies wishing to obtain or improve qualifications in NDE.

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