AC 2007-251: DEVELOPMENT OF NDE LABORATORY FOR AET STUDENTS AND CERTIFICATION PROGRAM

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Development of NDE Laboratory for AET Students and Certification Program

ABSTRACT

Drexel University's Goodwin College of Professional Studies is in the process of developing the instructional materials for its nondestructive evaluation (NDE) course by placing emphasis on techniques and applications in the areas of manufacturing, power generation, oil and gas production, structural and pipeline welding, and commercial/military aviation maintenance, among others. Students enrolled in the Bachelor of Science in Applied Engineering Technology (AET) program will be the main target audience. They will have access to the developed material in two modes: the traditional face-to-face classroom mode for those on Drexel's campus, and a real-time, Internet-based videoconferencing mode for those attending classes at remote locations, specifically students at community colleges partnering with Drexel. The developed instructional materials will be part of a wider STEM (Science, Technology, Engineering, and Mathematics) initiative, including the development of novel teaching and learning strategies, the creation of new learning materials, and the implementation of effective assessment and evaluation techniques. Additionally, these novel teaching and learning strategies will be incorporated into the curricula of Drexel University's two-year college partners, such as Burlington County College and Delaware County Community College. The outcome of the proposed project will be a hands-on laboratory course in which NDE techniques of parts and materials will be presented and applied through real-life problems. NDE curriculum will be designed to fulfill Levels I and II NDE in theory and training requirements, according to American Society for Nondestructive Testing (ASNT) Recommended Practice No. SNT-TC-1A (2001). Once fully developed, the NDE laboratory will serve as a training center for engineering technology students, as well as for the workforce of local companies, such as Boeing, Lockheed Martin, and PECO Energy, with whom Drexel has a rich history of partnership in terms of internships and research collaborations. Such educational laboratories are nearly non-existent in our geographic region, and consequently will be welcomed by the industrial community in need of engineering technologists who can competently utilize NDE instrumentation and to provide support to the designers and engineers in testing applications.

INTRODUCTION

Drexel University is the only institution of higher education in the Delaware Valley and Greater Philadelphia Region that offers a Bachelor of Science (B.S.) degree in Applied Engineering Technology (AET). One of the goals of Drexel's Applied Engineering Technology program is:

- To become a national model for the delivery of high-quality, affordable, technically-oriented education by focusing on student-centered learning and the integration of hands-on laboratory and industry-based experiences.

To achieve this goal and improve the learning, the Drexel's Goodwin College is in the process of expanding and upgrading its educational facilities by implementing a series of well-designed strategies and developing new state-of-the-art laboratories. These facilities will allow all AET students to be involved in the educational, research, and training process and also will alleviate the shortage of trained specialists in applied electrical, mechanical, and manufacturing technology. The key factor in the development process is the creation of educational laboratories that can significantly contribute to the development of technologically literate students and workforce. These value human resources could be in great demand, not only in the tri-state area but also nationwide[1].

OBJECTIVES AND SIGNIFICANCE

The objective of the proposed project is to develop a course with a problem-based learning approach to nondestructive evaluation (NDE) of materials using Internet Protocol (IP) networks for undergraduate AET students. This is a hands-on, three-credit course (within the frame of Drexel's quarter system) consisting of laboratory work each week with just in time lectures. The outcome of the proposed project will be a two-part course: the first part with an emphasis on the foundations of NDE, and the second part during which NDE techniques of parts and materials will be presented and applied through real-life problems. Specifically, the students will learn the engineering and physical principles of measurements of sound velocity in different materials, attenuation coefficients, directivity pattern of ultrasonic transducers, and location and dimensions of heterogeneities in various materials, such as holes, cracks, cavities, and flaws. The work in the laboratory will enhance the fundamentals taught in the classroom sessions.

The proposed ultrasound NDE educational laboratory will serve as a training center for undergraduate AET students, as well as for the workforce of companies, such as Boeing, Lockheed Martin, and PECO Energy, with whom Drexel has a rich history of educational and research partnership. After careful consideration and discussions with the largest employers in the Atlantic region, representatives of the ANST, and based on our research, educational, and engineering experience, we came to the conclusion that the creation of a unique ultrasound NDE laboratory would significantly benefit our students and working engineering personnel. The establishment of a state-of-the art laboratory for NDE purposes will allow Drexel and its community-college partners to develop training options for technicians located in the region's key industries. NDE curriculum will be designed to fulfill Levels I & II NDE in theory and training requirements, according to ASNT Recommended Practice No. SNT-TC-1A (2001)[2].

During the past two years, an introductory, laboratory-based course in ultrasound imaging was developed and offered at the undergraduate level in the School of Biomedical Engineering at Drexel University [3]. The course exposed students to basic applications of ultrasound measurements related to medicine, primarily through laboratory activities. Lecture time with students allowed for the introduction of topics included in the laboratory experience, such as measurements of sound velocity in different materials, attenuation coefficients, and directivity pattern of ultrasonic transducers. The objective of the proposed project is to implement the developed material into a format suitable for undergraduate AET students and expand it to an Internet-based course composed of an introductory laboratory course with a problem-based learning approach to NDE of materials. More specifically, the students will learn the engineering and physical principles of measurements of sound velocity in different materials, attenuation coefficients, directivity pattern of ultrasonic transducers, and location and dimensions of heterogeneities in various materials, such as flaws, cavities, layers, and holes. The industrial case studies in laboratory environment will enhance the fundamentals taught in the classroom sessions.

This course will be designed for undergraduates at the pre-junior or junior levels, but may also be taken by other undergraduate and graduate students who have fulfilled the necessary prerequisites and desire to obtain knowledge in the field of ultrasound NDE of materials. This approach will provide an excellent introduction to the manufacturing environment for the undergraduates, develop project leadership skills, and facilitate the development of teamwork that will allow the project to proceed without the constant supervision of the faculty advisor.

EFFECTIVENESS OF THE PROJECT

The need for a large number of practical engineers with background in service and quality-control analysis of industrial processes over the next decade has been clearly outlined[4,5,6]. The proposed project provides a mechanism for giving undergraduate AET students direct, hands-on experience with quality-control analysis in various manufacturing fields, such as inspection of aircraft wing section, in-process testing to determine the thickness and bond quality of a carbide wafer bonded to the top of a steel valve after grinding, rocket motor inspection, small diameter tube inspection, and transportable large-diameter tube inspection[7,8,9]. Students who complete the course will gain an understanding of the use of ultrasonic NDE equipment, tools for ultrasonic imaging, and electronic measurement equipment. They will gain direct, hands-on experience with some of the tools available for inspection of products and equipment and will carry out experiments on their own. Students will study current literature on topics related to their laboratory work and other related areas. In this way, students will gain an appreciation for experimental procedure, which will expand their future employment opportunities.

Efforts to make the program cost-effective will include the following:

- Utilize Internet access to high-end equipment for other universities and community colleges[10,11]. Thus, the experience of performing the experiment would be essentially the same for students in the room with the instrument or students at remote locations. Through remote operation, expensive equipment can be made accessible to institutions that cannot afford the equipment directly and which do not have faculties with the expertise in ultrasound NDE area.

- Develop a team approach in the laboratory creating a model for a real-world environment.

- Develop training and certification programs for the manufacturing and operating companies who desire to train or retrain their workforce in the field of NDE of materials.

- Involve students in research activities related to ultrasound measurements and nondestructive testing, which will lead to advancement in their careers.

STUDENT PERSPECTIVE AND SAMPLE PROJECTS

This course will be a three-credit course consisting of lecture and laboratory work each week. Laboratory sessions will be organized around current developments in the field of ultrasound NDE of materials. Measurement procedures and experiment descriptions will be adapted and implemented from the NDE educational material for the website and for delivery to other community college programs, such as welding, manufacturing, and aviation maintenance. Students will work as teams to research the problem, develop possible approaches to solving the problem, and begin to structure possible solutions. During the laboratory sessions, students will be introduced to tools, methodologies, and techniques that may be useful to solving the problem. Finally, students will carry out experiments they have designed and describe their results in individual reports for each laboratory session. After completion of all laboratory sessions, each team would be responsible for writing a final report that summarizes the current state in the area, describes the experimental techniques utilized, discusses the expected outcomes, provides data of the actual outcomes, and explains the reasons for the departures between the expected and the actual results. The team would analyze the data, draw conclusions, and suggest possible ways for improving the accuracy of their experiments. The team members would then present their findings to the class as a whole.

A new educational laboratory for ultrasound measurements (UM) and NDE is to be developed to serve primarily students pursuing a B.S. degree in AET. The state-of-the-art facility also will be designed to serve working individuals interested in improving their skills in UM and NDE, as well as those seeking knowledge for professional advancement. Two workstations already installed consist of the following equipment (Fig. 1):

- DAEDAL XYZ Θ Scanning System (800 mm x 900 mm x 350 mm Travel)
- Pulser/Receiver: Panametrics Pulser/Receiver 5073 PR
- Three pairs of ultrasonic transducers with different resonant frequencies
- Oscilloscope: Tektronics TDS220 Digital with the GPIB board
- Pentium PC.

Fig. 1. Ultrasound measurements workstation

The experiments described below are presently carried out using the installed equipment:

1. Measurements of the sound velocity in water

Most applications for underwater acoustics, nondestructive testing 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 (the time-of-flight)[12]. 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 the associated electronics. The placement of the transducers is controlled by the Lab View virtual instrument (*V I*) (Fig. 2). Collected data is transferred to the computer under control of Lab View *V I* and saved as a text file for future processing using Microsoft Excel.

2. Measurements of the sound velocity in other materials

The propagation velocity of traveling waves is a characteristic of the media in which they travel and is generally not dependent upon the other wave characteristics such as frequency, period, and amplitude[13]. Three pairs of transducers are used in this laboratory session to confirm these statements. The Plexiglas plate and three various rubber plates are used for determining the sound velocity in these materials using the through-transmission configuration. The distance between transducers is larger than the thickness of the sample material, allowing a free alignment and positioning of the sample along the ultrasonic beam. The measurement system consists of a pair of coaxial transducers of similar frequency characteristics, here denoted as a transmitter and a receiver (hydrophone), and a sample material placed between them. The whole system is immersed in a water tank.

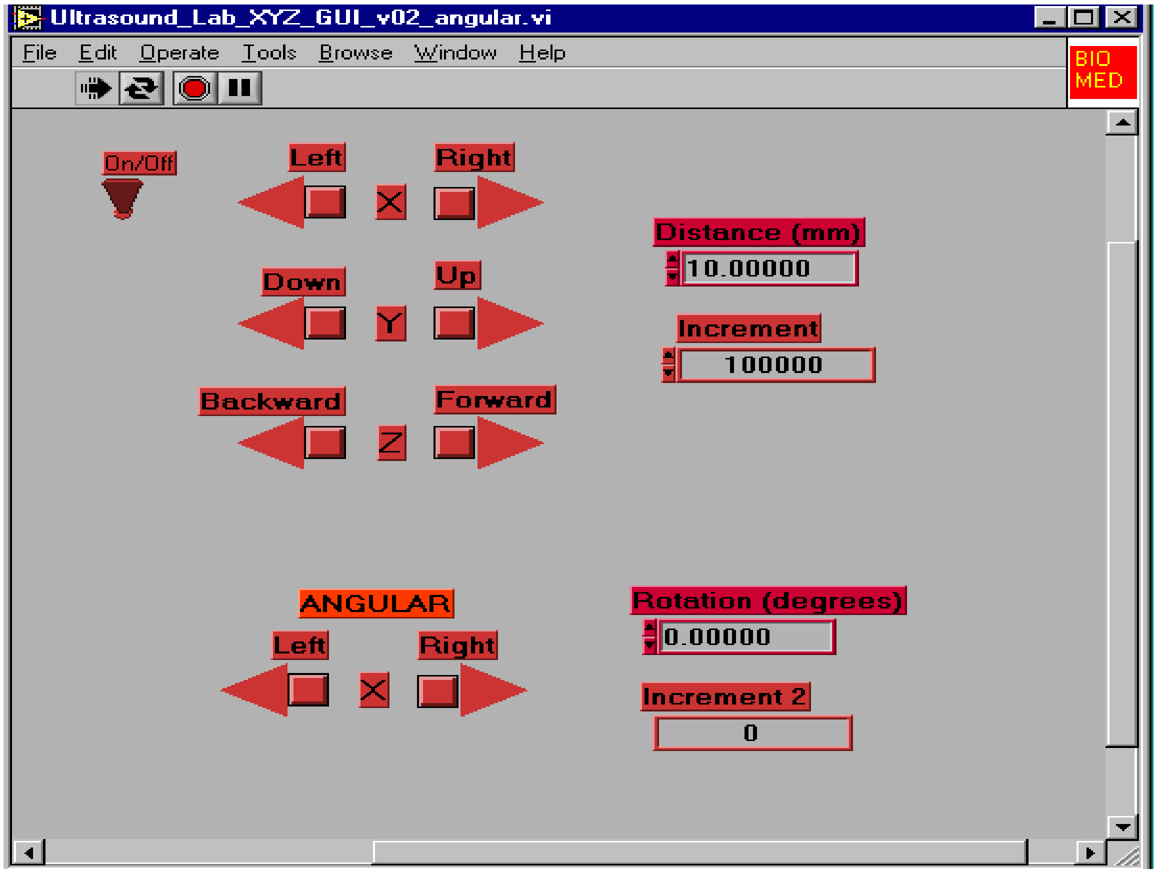

Fig. 2. Lab View Controller.

The following two methods for measurements of the sound velocity in the samples are used:

Method 1—The transit time, τ_1, of the received signal is recorded by the oscilloscope without placing the sample material between the transducers. Then, the sample material is placed between the transducers, and the transit time, τ_2, of the received signal is recorded again. The sound velocity in the sample material can then be easily determined.

$$c_m = \frac{d}{\frac{d}{c} - \Delta\tau}, \qquad (1)$$

where c is the sound velocity in water (m), which was previously determined, d is the thickness of the sample material (m), and $\Delta\tau = \tau_1 - \tau_2$ (s)

Method 2—The arrival time of the received signal is recorded by the oscilloscope without placing the sample material between the transducers. Then, the sample material is placed between the transducers, and the receiver is moved back from the transmitter by a distance equal to the thickness of the sample material. The procedure described for each method is repeated for three types of rubber plates with different thicknesses. In the final report, students will be expected to clearly state the advantages and disadvantages of both methods and compare the results obtained by both methods. The technique described above can be also used for measuring the thickness of the sample materials, as well as the dimensions of heterogeneities in the sample materials, such as cracks, holes, and cavities.

$$c_m = \frac{d}{\Delta \tau} \qquad (2)$$

3. Directivity Pattern Measurements

The directivity pattern is an important far-field characteristic of an ultrasonic transducer[14,15]. In this laboratory session, the directivity pattern is determined analytically and also measured experimentally. Three pairs of transducers with different resonance frequencies are used in these experiments. Directivity pattern measurements are carried out with the hydrophone (receiver) fixed and the transmitter rotated using Lab View. For each angle, the peak-to-peak voltage of the received signal is recorded, and the data are saved in the computer as text files. Results of the computed and measured directivity patterns at 2.25 MHz, 3.5 MHz, and 5 MHz are presented in Fig. 3.

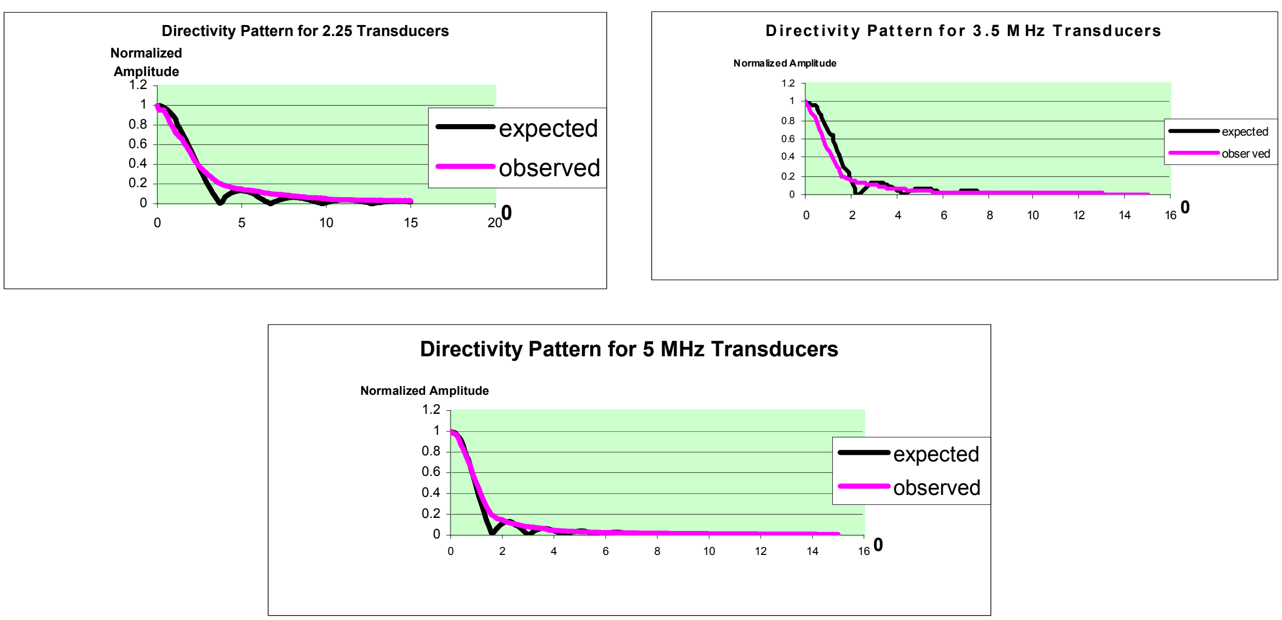

Fig. 3. Computed and measured directivity patterns.

4. Measurements of the attenuation coefficient of the ultrasonic waves in Plexiglas

The attenuation of a wave is determined by scattering and absorption, which are properties of the medium through which the wave passes[13,16]. Since the scattering and absorption are frequency dependent, attenuation can be used in the quality control of the materials. In this laboratory session, the immersion technique is used for the measurements of the attenuation coefficient in Plexiglas. Three Plexiglas plates, which have the same mechanical and physical properties and different thicknesses, are used in the experiments. At least two samples of the Plexiglas are required for the experiment, since the reflection coefficient of the Plexiglas is not known and should be eliminated from the evaluation of the attenuation coefficient. The peak-to-peak voltage of the received signal is recorded by the oscilloscope and is saved in the computer. Measurements are repeated with two other sets of transducers and the attenuation coefficient in dB/cm/MHz is determined.

Feedback from the students who took this course indicated that this course has been extremely effective; this information was recorded in students' course evaluation forms. Most of the students indicated that this was one of the best hands-on experiences they have ever had. Such a positive course evaluation record and willingness to develop quite a unique course for AET students encourages faculty of the Goodwin College to adapt and implement this laboratory course with the emphasis in ultrasound NDE of materials, which would benefit manufacturing and service companies involved in quality-control analysis process. In order to incorporate the NDE of materials into the AET program, the laboratory, in addition to the existing equipment described above, was equipped by the following devices: Automatic Flaw Detectors USN58L, USM35X, and USLT2000 (Fig. 4), which allow the following experiments to be implemented[17]:

- Evaluation of homogeneity of various materials used in industrial applications
- Detection and localization of heterogeneities in the materials, such as flaws, cavities, layers, and holes[18,19,20,21]
- Measurement of the dimensions of various parts and components, where conventional methods (such as rulers and calipers) cannot be applied
- Diagnostic evaluation of the structures of various materials by measuring the sound speed and attenuation

Fig.4. Automatic Flaw Detectors USN58L, USM 35X, and USLT2000 (from left to right)

The first course, MET 380 (NDE of Materials), was offered as a special topic course during the winter term of the 2005-2006 academic year. Students were engaged in the weekly experiments using equipment described above, along with newly purchased automatic flaw detectors from GE Inspection Technologies, such as USN 58 and USM 35. During the laboratory sessions, students were able to control NDE devices via computers allowing integration of the experiments with Internet-based automation technologies.
Specifically, the following experiments were carried out:

1. Calibration of the flaw detectors using **Straight-Beam** probes utilizing the instruments' **AUTO-CAL** feature. Straight-beam probes, either single-element probe or dual-element probe, can be used for material thickness measurements. The description of the experiment using the USN 58 flaw detector and a dual-element probe is described below. During the procedure, students set the display **RANGE** so that two reference calibration echoes from different material thicknesses (Fig. 5) are displayed on the screen.

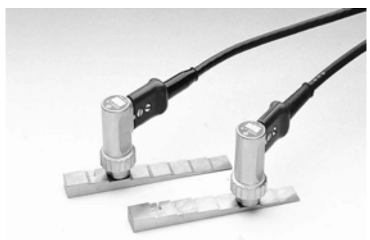

Fig.5. Calibration of the flaw detectors using a straight-beam probe

In the **CAL** Menu, the two calibration reference distances are entered as **S-REF1** and **S-REF2** with **S-REF1** being the thinner reference thickness and **S-REF2** being the thicker reference thickness. The transducer is placed on the THINNER reference and the key is pressed to record the reading. The recording of the first calibration echo is confirmed by the message "ECHO is RECORDED", and the thickness of the calibration block is recorded on the display (Fig. 6). Then, the transducer is placed on the THICKER reference and the key is pressed. The recording of the second calibration echo is also confirmed by the message "ECHO is RECORDED", and once again the thickness of the calibration block is recorded on the display (Fig. 7).

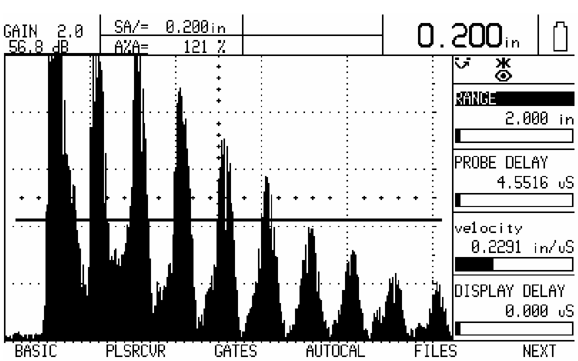

Fig. 6. First calibration echo

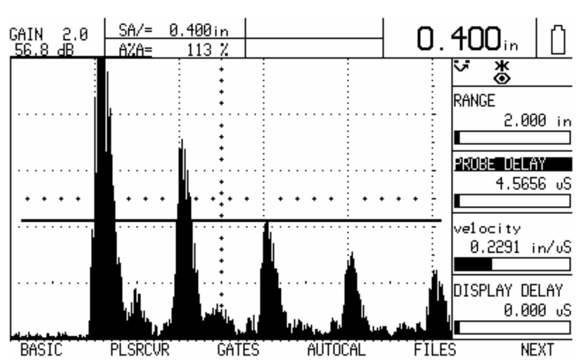

Fig. 7. Second calibration echo

The correct calibration is confirmed by the message “CALIBRATION IS DONE”. The flaw detector will now automatically determine the sound velocity and probe delay for the transducer and material being used in this procedure. These values will be set to the corresponding functions accordingly.

During the calibration procedures, the following ***rule*** should be implemented: *Use a work piece of the same material as the test object whose dimensions are known.* By coupling the probe onto an object of known thickness, t, an echo sequence appears on the display.

2. Wall thickness measurements and the detection of near-to-surface discontinuities (Fig. 8). After the calibration of the instrument, the detection of discontinuities is carried out with the same instrument and the same probe according to the ***rule*** described above.

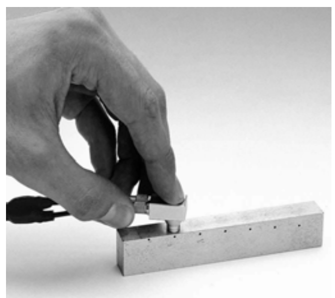

Fig.8. Detection of near-to-surface discontinuities

3. Calibration procedure with the **Angle-Beam** probe for Wedge Angle Verification, Sound Path Distance Calibration, and Flaw Sensitivity Calibration using an IIW (International Institute of Welding) type 1 calibration block is presented below (Fig 9).

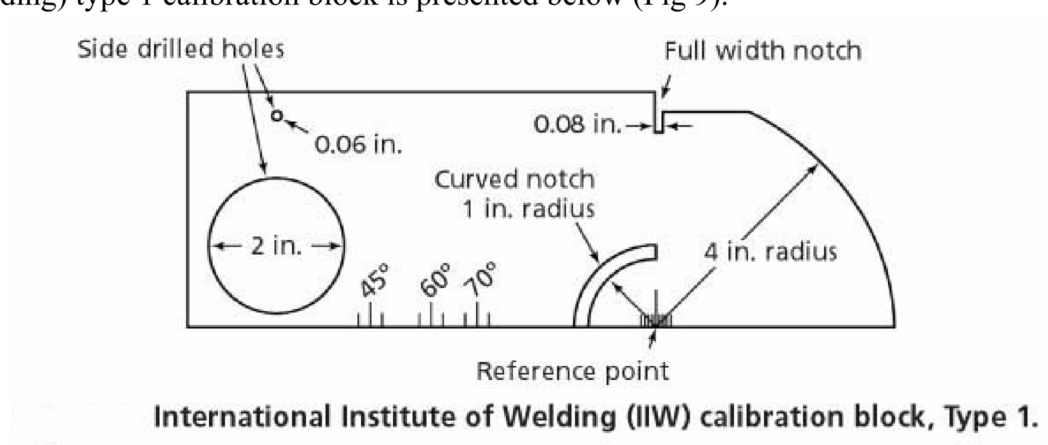

Fig. 9. IIW calibration block

Using the flaw detector’s **TRIG** Menu, the student enters in the following information to set up the angle-beam flaw position calculations (Fig. 10):

a. Probe Wedge **ANGLE** (Angle of Incidence) 45^o through 90^o. This value is required for the calculation of the flaw position (S).
b. **X-VALUE** is the distance between the probe’s front edge and the Index or Sound Exit point on the wedge (X). PD is the Projection Distance.

c. **MAT THICK** is the base material's wall thickness. This value is required for the calculation of the Depth Distance, d.

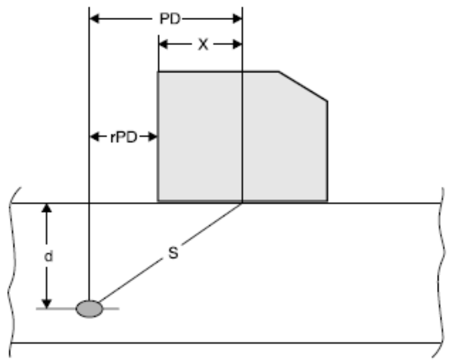

Fig.10. Distance or Sound Path calculations with an Angle Beam Test

Students place the transducer at various positions on the IIW block (Fig. 11) to display reflections from sound path distances and sensitivity relationships to side drilled holes.

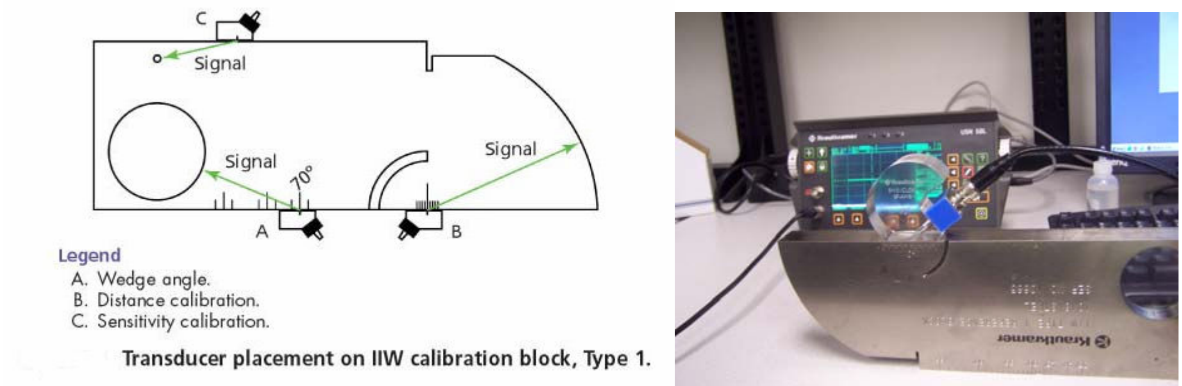

Fig. 11. Calibration with the angle-beam probe for sound Distance and Flaw Sensitivity using an IIW calibration block

The results of the calibration procedure using an angle-beam probe are presented in Fig. 12.

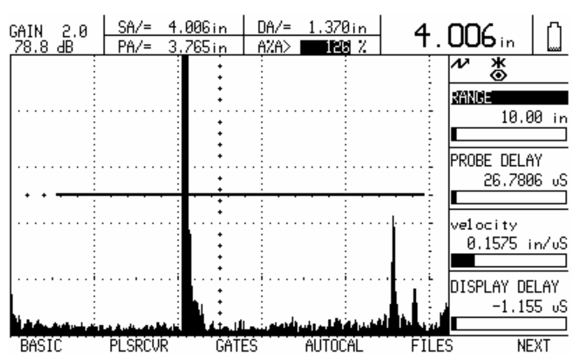

Fig.12. Results of the calibration procedure using an angle-beam probe

CONCLUSION

During the current winter term of the 2006-2007 academic year (January 2, 2007 – March 23, 2007), the newly redesigned course EET-203 (Nondestructive Evaluation of Materials) is being offered to pre-junior AET students. The industrial partners, in collaboration with the faculty, developed real-world industrial problems. Mr. Tony Midora of Precision Measurement Technology Inc. participates in providing instruction during the laboratory sessions. The authentic problems were presented to the faculty who were responsible for the final phrasing of the given task, such that the description of the task, including the objective of the project, its motivation, and the expected deliverables are clear and understood by the students. Specific steps of faculty-industry collaboration were:

1. The industrial collaborators presented the draft of the project and description of the laboratory experiment to the faculty.
2. The drafts were reviewed by the faculty and will be presented to the Industrial Advisory Committee for suggestions, corrections, and changes.
3. Drafts were amended and returned to the industrial contacts for their final approval.
4. Projects, experiments, and manuals are currently available for the students.

The industrial collaborators also provided samples of parts and materials used for inspection. For example, PMT Inc., the local representative of GE Inspection Technology, donated to the AET program three parts of a large diameter pipeline, which are used for calibration of flaw detectors in the NDE of the pipelines. Sonaspection International Inc. supplied the welding samples, which are used for detection and characterization of the weld's defects. Westech Inspection Inc. provided the sample of a portion of a pipe covered by corrosion.

The work in the laboratory enhances the fundamentals taught in the classroom sessions. After completion of all laboratory sessions, the students will become familiar with basic acoustical instrumentation, possess hands-on experience with ultrasonic and electronic equipment, and will be able to demonstrate the basic principles of ultrasound imaging and NDE techniques. An important objective of this laboratory is to improve the students' knowledge of data gathering, the identification of sources leading to erroneous measurements, and proficiency in communication skills. Therefore, a concise written report clearly describing all conclusions and comments is required within seven days after completion of each laboratory session. Students work in teams on projects drawn from several areas of technological interest. The simulation of the NDE applications used by companies in industry is implemented in the proposed project. A qualified evaluator from industry will make an evaluation of the success of the course based on the students' laboratory reports, the final report, and the final presentation. The students who demonstrate the level of competence required by industry will receive the certificate of qualification in ultrasound NDE of materials.

This project is still under development. Additional NDE equipment will be purchased and installed. Projects and experiments will also be available for the students online. During the development of this project, more experiments and case studies will be added to this course. New developments will be incorporated into the conference presentation.

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