NDE EDUCATION AND TRAINING FOR ENGINEERING AND ENGINEERING TECHNOLOGY PROGRAMS

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Abstract

The purpose of this paper is to present an innovative approach to teach both theory and practical industrial applications of the Nondestructive Evaluation (NDE) of materials. There is a well-defined need for such training as the industry is becoming increasingly reliant on the NDE technology, which creates a growing demand for graduates familiar with this field. At the recent meetings of the American Society for Nondestructive Testing (ASNT), the employers constantly emphasized their urgent need for employees with knowledge and experience in the state-of the art computer-based data acquisition and analysis NDE systems. The NDE of materials course was developed for Applied Engineering Technology (AET) students at Drexel University's School of Technology and Professional Studies. This four-credit, hands-on course consists of two parts: the first part stresses the foundations of ultrasound based NDE and the second part focuses on calibration and testing practice. Selected specific NDE applications are presented and discussed in-depth, so the students are gaining insight into the advantages and fundamental limitation of the NDE applications. Particular attention is given to detection and localization of discontinuities such as flaws, cavities, layers, and holes in different materials using state-of-the-art instrumentation. The students learn engineering practice and physical principles of measurements of sound velocity in different materials, attenuation coefficients, material thickness, and location and dimensions of discontinuities in a variety of materials. Laboratory sessions are carefully designed to complement the theoretical background presented to the students during classroom sessions. The course is designed to markedly improve the graduates' skills in the field of NDE utilizing portable ultrasound technology. Upon completion of the course the students undergo a final, comprehensive testing, which aids in their retention of acquired knowledge and testing skills. The course is primarily targeting the undergraduate AET students at the sophomore, pre-junior, or junior levels, however, both undergraduate and graduate Drexel students from other Colleges can enroll providing they comply with the mandatory set of prerequisites. The same acceptance procedure is applied to the students from other universities and community colleges.

Key words: *Nondestructive evaluation, applied engineering technology, discontinuities.*

1. INTRODUCTION

For more than five years, Drexel University's Goodwin College has been offering the Applied Engineering Technology (AET) major to full- and part-time students at Drexel University and also as a dual enrollment program to the students of Delaware County Community College

(DCCC), Pennsylvania and Burlington County College (BCC), New Jersey. AET program comprises three concentrations: Electrical, Mechanical, and Industrial Engineering Technologies. The program's curriculum places emphasis on the application of theory rather than on derivations and proofs. The majority of courses are fully integrated with training and laboratory experience, including extensive use of software and industrial case studies. Goodwin College is in the process of expanding and upgrading its educational facilities. Several state-of-the-art laboratories were created to provide hands-on education and training to students who are pursuing a degree in AET with a concentration in electrical, mechanical, or industrial engineering technology. AET laboratories are used extensively for most of the program's courses, including the newly developed course in Nondestructive Evaluation of Materials (EET 203). This course consists of two parts: the first part with an emphasis on the foundations of NDE, and the second part, during which nondestructive evaluation techniques of parts and materials are presented and applied through real-life problems. Specifically, the students 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 discontinuities in various materials, such as holes, cracks, cavities, and flaws. The work in the laboratory enhances the fundamentals taught in the classroom sessions. The outcomes of this project will lead to improvements in the education process, since industry is becoming increasingly reliant on the effective application of NDE technology, and the demand on the NDE specialists is increasing.[1,2]

2. COURSE AND LABORATORY DEVELOPMENT

The developed NDE educational laboratory will serve as a training center for undergraduate AET students as well as for the workforce of companies involved in NTD applications. After careful consideration and discussions with the largest employers in the Atlantic region and representatives of the American Society for Nondestructive Testing (ASNT), along with our own 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. Such educational laboratories are almost non-existent in the Tri-State geographic area (PA, NJ, and DE) and would be welcomed by the working community. 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 is designed to fulfill Levels I & II NDE in theory and training requirements, according to ASNT Recommended Practice No. SNT-TC-1A, 2006.[3]

NDE is one of the most powerful and cost-effective techniques for quality and safety control of structures, parts, and products. NDE of materials and components is crucial to aerospace, naval, railroad, and other industries. For example, aerospace designers and manufacturers are frequently faced with the need to validate the integrity of structural parts for military and commercial aircrafts.[4] Transportation equipment is highly specialized and safety sensitive; therefore, it is important that all aspects of a failure are investigated, not only for the purpose of classifying the failure mode but also to determine its cause from an engineering mechanics and design point of view. Similar issues exist in other areas, such as maintenance and diagnostic techniques for nuclear power plants and petrochemical industry. The NDE course was designed in response to the requirements of local and regional industries in need of such techniques, and more importantly, of qualified personnel. Due to its distinctive nature, Drexel's Applied Engineering Technology program is uniquely positioned to incorporate NDE courses as part of its curriculum, thus creating the necessary knowledge and experience among its students and graduates.

During the development of this course, representatives from several companies enthusiastically expressed their interest in participation in this project. Specifically, Mr. Rich Bottari, the manager of Boeing, Inc. and Mr. Tony Midora of GE Inspection Technologies, Inc. agreed to provide the guidance for designing the experiments and conducting evaluations of the students' competence. The simulation of the NDE applications used by companies in industry was implemented in the project. A qualified evaluator from industry will determine the success of the course based on the students' laboratory reports, the final report, and the final presentation upon completion of all laboratory sessions. Moreover, the industry partners suggested providing the Certificate of Qualification to the students who demonstrated the level of competence required by industry (ASNT Recommended Practice No. SNT-TC-1A, 2006). Based on these recommendations, evaluation reports, and student course evaluation forms, the necessary changes in the course guidance and laboratory procedures will be implemented. In addition, the industrial partners, in collaboration with the Drexel's faculty, developed real-world industrial problems and provided instruction during the laboratory sessions (Figure 1).

Figure 1. Mr. Tony Midora and Mr. Richard Bottari provide instruction during the laboratory sessions.

The suggested laboratory experiments were presented by the industrial partners to the faculty 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 with the timeline were clear and understood by the students. The industrial collaborators also agreed to provide samples of parts and materials used for inspection (Figure 2). For example, PMT, Inc. (New Jersey), the local representative of GE Inspection Technologies, donated three parts of large diameter bearings, which are used for calibration of flaw detectors in the NDT procedures. Sonaspection International, Inc. of North Carolina supplied the welding samples, which are used for detection and characterization of the weld's defects.

Figure 2. Large diameter (320 mm) bearing (left) and welding samples (right).

During the laboratory sessions, the students 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 discontinuities in various materials, such as flaws, cavities, layers, and holes. The industrial case studies in laboratory environment enhance the fundamentals taught in the classroom sessions. After completion of all laboratory sessions, students become familiar with basic ultrasonic instrumentation, gain hands-on experience with ultrasonic and electronic equipment, and are able to demonstrate the basic principles of ultrasound imaging. Students also become familiar with the practical methods and techniques of NDE used in the industry, improve their problem-solving capabilities, carry out laboratory procedures with guidance from an instructor, and describe the purpose of the procedures and the results in their laboratory reports. This approach provides an excellent introduction to the manufacturing environment for the undergraduates, develops project leadership skills, and facilitates the development of teamwork. The NDE course was developed for undergraduates at the sophomore, pre-junior, or junior level, and may also be taken by other undergraduate/graduate students at Drexel or by the students of other universities and community colleges who have fulfilled the necessary prerequisites and desire to pursue a bachelor of science (B.S.) degree in AET or obtain training in NDE.

3. LABORATORY PROCEDURES

The four-credit, quarter-based (eleven weeks) NDE course consists of lecture and laboratory work each week. Labs are organized around current developments in the field of ultrasound NDE of materials. During the laboratory sessions, students are introduced to tools, methodologies, and techniques that may be useful to solving the problem. Finally, students carry out experiments, evaluate their results using various methods and techniques, and describe the results of the experiments in individual reports for each laboratory session. After completion of all laboratory sessions, each team is 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 teams analyze the data, draw conclusions, and suggest possible ways for improving the accuracy of their experiments. The teams then present their findings to the class as a whole. The following experiments are carried out during the laboratory sessions:[5]

3.1. Measurements of the sound velocity in water

Most applications of NDE of materials 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).[6] During this laboratory, the two sets of measurements are carried out: (1) Using one transducer, which is used as transmitter/receiver, and the reflector, and (2) Using two transducers, where one of them is used as a transmitter and the other one is used as a receiver. The results obtained using both techniques are later averaged.

3. 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.[7] The measurement system is immersed in a water tank and consists of a pair of piezoelectric transducers of similar frequency characteristics. The transit time of the received signal is recorded without placing the sample material between the transducers. Then, the sample material is placed between the transducers and the transit time of the received signal is recorded again. The sound velocity in the sample material can then be easily determined.

3. 3. Directivity Pattern Measurements

The directivity pattern is an important far-field characteristic of an ultrasonic transducer. [8,9] In this laboratory session, the directivity pattern is determined first analytically and then experimentally. Three pairs of transducers with different resonant frequencies are used in these experiments. Directivity pattern measurements are carried out with the receiver fixed and the transmitter rotated using a stepper motor. 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.

3. 4. Measurements of the attenuation coefficient of the ultrasonic waves

The attenuation of an ultrasound wave is determined by scattering and absorption, which are properties of the medium through which the wave passes.[7,10] The known value of attenuation can be used in the quality control of the materials, such as distance-amplitude calibration procedures.

3. 5. NDT procedures

In order to incorporate the NDE procedures, the laboratory was equipped by the following devices: Portable Ultrasonic Flaw Detectors USN 58L and USM 35X
(Figure 3), which allows the following experiments to be implemented [11]:

- Calibration of automatic flaw detectors
- 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[12,13,14,15]
- Measurement of the dimensions of various parts and components, where conventional methods (such as rulers and calipers) cannot be applied

Figure 3. Portable Ultrasonic Flaw Detectors USN 58L and USM 35X (from left to right).

Students were engaged in the weekly experiments using equipment described above. Specifically, the following experiments were carried out:

1. Calibration of the flaw detectors using **Straight-Beam** single-element or dual-element probes utilizing the instruments' **AUTO-CAL** feature. During the procedure, students set the display **RANGE** so that two reference calibration echoes from different material thicknesses (Figure 4) are displayed on the screen (Figure 5 and Figure 6).

Figure 4. Calibration of the flaw detectors using a straight-beam probe.

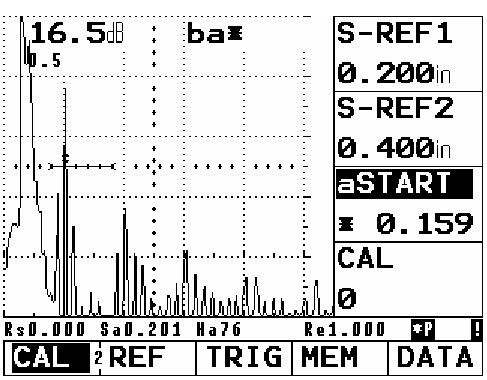

Figure 5. First calibration echo.

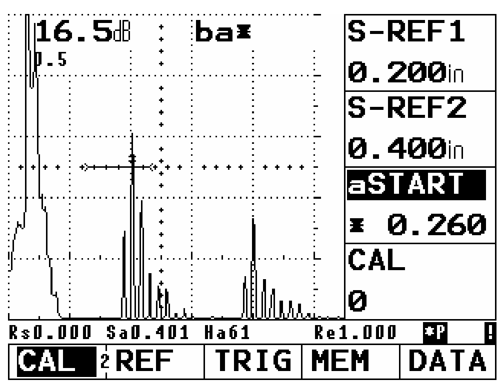

Figure 6. Second calibration echo.

The correct calibration is confirmed by the message "**CALIBRATION IS DONE**." The flaw detector then automatically determines the sound velocity of the material being tested in this procedure and the probe delay.

2. Evaluation of the resolution of the system, i.e. the ability of the system to differentiate two or more discontinuities closely spaced in a lateral plane (Figure 7). After the calibration of the instrument, the detection of discontinuities is carried out with the same instrument and the same probe.

Figure 7. Evaluation of the resolution of the system.

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 (Figure 8).

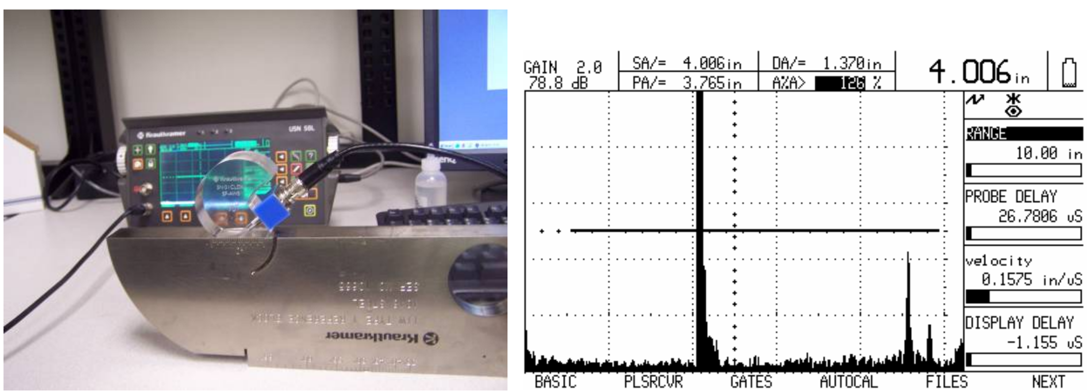

Figure 8. A. Calibration setup using angle-beam probe and the International Institute of Welding calibration block for. B. Results of the calibration procedure using an angle-beam probe.

After calibration of the instrument, students place the transducer at various positions on the IIW block (Figure 8) to display reflections from side drilled holes and evaluate sound path distances and sensitivity relationships. In addition, the students were able to detect and evaluate various defects in welds.

4. Evaluation of the dimensions and shapes of various discontinuities

After calibration of the instrument using a straight-beam probe, the surface of the test object was scanned and the position of the transducer on the test object, at which the echo amplitude drops by half (6 dB drop), was recorded. This indicates that the acoustic axis of the transducer is on the boundary of the discontinuity. Scanning the transducer on the surface of the test object, students determined other boundary points and drew the contour of the discontinuity. The drawing was compared with actual shape and size of the discontinuity (Figure 9).

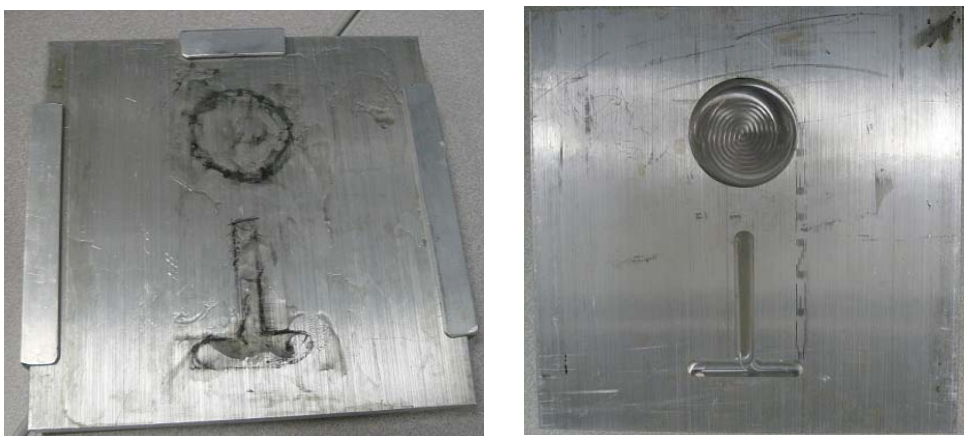

Figure 9. Students' drawing (left) and actual discontinuities (right).

Upon completion of all laboratory sessions, each team was responsible for writing a final report that described the experimental techniques utilized, discussed the expected outcomes, provided data of the actual outcomes, and explained the reasons for the discrepancies between the expected and the actual results.

4. REMOTE CONTROL OF THE NDT EQUIPMENT

One of the main goals of the project is to develop a videoconference teaching NDE facility, which will provide greater program delivery flexibility and offer non-traditional educational segments.[16,17,18] This facility will allow all AET students at Drexel, as well as students at remote locations, to be involved in the same educational and training process in NDE. By expanding training opportunities to students who might not otherwise take advantage of them, due to distance and time, this facility helps reduce the shortage of trained specialists in NDE field. Key factors in the development process include creation of the educational laboratory that can significantly contribute to the development of technologically literate students and workforce that will be in great demand nationwide. The fully-interactive videoconference teaching course in NDE is being developed for undergraduate AET students and may also be taken by other undergraduate/graduate students at Drexel or by the students of other universities and community colleges who have fulfilled the necessary prerequisites and desire to pursue a BS degree in AET or obtain training in NDE. This approach will facilitate the development of teamwork that will allow the project/laboratory to proceed without the constant supervision of the faculty advisor.[19] The inter-institutional class sessions will be carried out utilizing Internet2-based access to the equipment of Drexel's NDE laboratory for other universities and community colleges. Students involved in the "live" interaction with other participants will share in small group discussions, collaborate, and fully engage in the videoconferencing experience. The implications of fully-interactive videoconference teaching are far-reaching as they relate to distance delivery of real-time interactive instruction between any remote sites subscribing to Internet2 services using Internet Protocol (IP) networks. The state-of-the-art NDE facility is also designed to serve working individuals interested in improving their skills in NDE, as well as those seeking knowledge for professional advancement.

Real-time remote control of USN 58L and USM 35X devices is under development. GE Inspection Technologies' UltraDoc software allows for control and data transfer to and from the portable ultrasonic flaw detectors. UltraVNC (Virtual Network Computing) software enables remote control and data transfer from the local computer connected to the Flaw Detectors and the camcorder simultaneously. Utilizing UltraVNC and UltraDoc control function and commands, one can remotely control and change any setting of the Flaw Detectors, such as calibration of flaw detectors and evaluation of the test objects. This configuration of equipment and software packages allow students at the remote site for participation in the laboratory activities. Technician's or teaching assistant's presence at the local site is required for initial set-up of the videoconferencing and NDE equipment and handling of the transducers. The calibration of the NDE equipment and testing procedures can be completely controlled from the remote site. Results of the calibration and testing can be saved from both local and remote computers. The block diagram of the remote NDE procedure is presented in Figure 10.

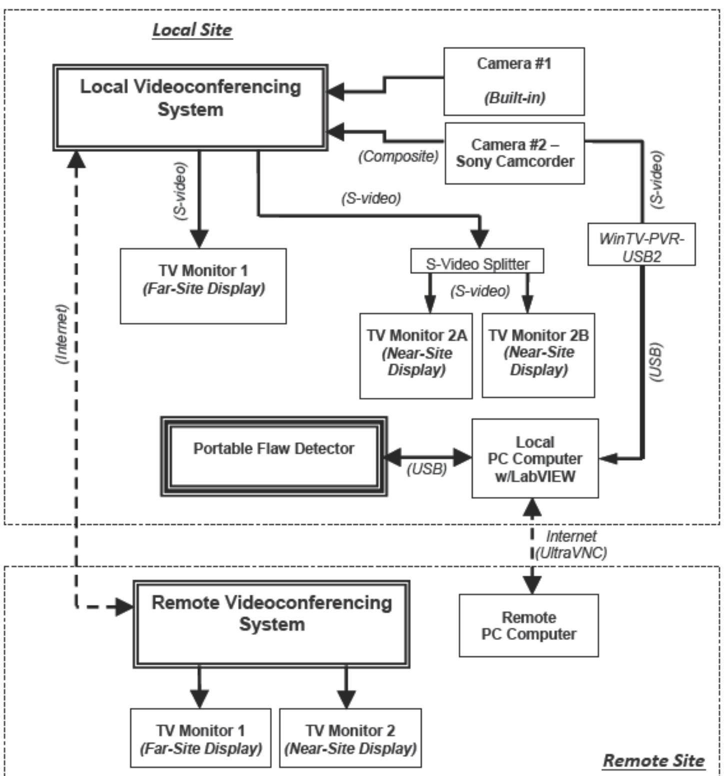

Figure 10. Block diagram of the remote NDE procedure.

5. COURSE EVALUATION

The described course has been designed with educational objectives and learning outcomes based on the general criteria of ABET (Accreditation Board for Engineering and Technology) for engineering technology programs. Multiple assessment measures have been implemented and documented to demonstrate that the course objectives and outcomes are being met. A description of the assessment and evaluation is provided below.

The EET-203 Nondestructive Evaluation of Materials course was offered since 2007-2008 academic year two-three times per academic year. Evaluation of the course and data collection began soon after the start of the term. Students who enrolled in EET-203 were administered a pre-test, which assessed the entering knowledge requirements for the course. Students' knowledge of appropriate algebra, trigonometry, and vibrations and sound waves were evaluated. Based on the results of the test, students were divided into four groups according to the "think-share-report-learn" (TSRL) process, which involved peer coaching to help each other during the laboratory procedures. The effectiveness of this approach to teaching the problem-based hands-on learning model within a virtual environment of a state-of-the-art laboratory for NDE purposes was evaluated using both formative and summative evaluation.[20] A formative evaluation assessed initial and ongoing project activities based on the students' tests, laboratory reports (which were required within seven days after each laboratory session), and class discussions. A summative evaluation assessed the quality and impact of an implemented project based on the students' final presentations, including corrections of the collected results and conclusions, and course evaluations. Industrial evaluators were involved in both formative and summative evaluations. Based on their recommendations, the laboratory procedures were modified according to the requirements of ASNT. After completion of all laboratory procedures, students completed a course evaluation form, which assessed the students' perception of their confidence, knowledge, and competence.

6. SUMMARY

The EET-203 (Nondestructive Evaluation of Materials) course was offered to pre-junior and junior, and senior AET students since 2007-2008 academic year. The industrial partners, in collaboration with the faculty, developed real-world industrial problems and participated in providing instruction during the laboratory sessions. Based on the feedback from the industrial collaborators and students' course evaluations, the necessary changes were made in laboratory procedures. The industrial collaborators also provided samples of parts and materials used for inspection. After completion of all laboratory sessions, the students became familiar with basic acoustical instrumentation, possessed hands-on experience with ultrasonic and electronic equipment, and were able to demonstrate the basic principles of ultrasound measurements and NDE techniques. An important objective of this laboratory was 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 was required within seven days after completion of each laboratory session. Students worked in teams on projects drawn from several areas of technological interest. The simulation of the NDE applications used by companies in industry was implemented in the proposed project. Qualified evaluators from industry made an evaluation of the success of the course based on the students' laboratory reports, the final report, and the

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