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Incorporating Non-Destructive Inspection Technologies into Engineering Technology Curricula to Meet Industry Needs

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Abstract

This paper details the curricular developments made over the years to an undergraduate-level non-destructive inspection (NDI) course and its complementing labs to better prepare undergraduates as they get placed in regional workplaces. The core motivation for this course as well as its development activities have been driven by the needs of the regional aerospace and oil & gas industry sectors, which was further affirmed via feedback from industrial advisory boards that convene each semester as part of the Manufacturing & Mechanical Engineering Technology (MMET) program, within the Department of Engineering Technology & Industrial Distribution at Texas A&M University (TAMU). Over the years, NDI has become an integral part of the design, manufacturing and maintenance procedures of components/systems utilized within these industries, many of which are large sized, of low-batch-size, and are high-value parts/systems. Consequently, NDI techniques have evolved to cater to the such environments, which often involve non-traditional and high-temperature materials. To meet this regional workforce demand for a graduate with such knowledge and skills, this specific core course was developed within the degree program which focused on five core NDI techniques that are state-of-the-art and relevant to these industry sectors. For this, technical material was assimilated, and counterpart lab activities were developed as part of a 400-level dedicated undergraduate course (senior-level). Being the only hands-on NDI lab of its kind on campus, its capabilities are also often highlighted as part of mini workshops for visiting students and during tours for industry visitors. This paper outlines the core NDI technologies selected for instruction as well as the lab activities designed to empower undergraduate students to be well-versed in NDI that are pertinent for the regional industry needs. Qualitative feedback from students was also gathered to ascertain the reception of the content and the learning experience.

Introduction

Non-destructive inspection (NDI), often also referred to as non-destructive evaluation (NDE) or non-destructive testing (NDT), is an approach that is used to detect defects (or discontinuities) in materials within structures/parts, such as pores/voids, cracks, secondary materials such as inclusions and impurities, etc. – the NDI approach achieves such detection without causing any appreciable damage or imposing significant harmful effects in the specimens being inspected, resulting in part reusability after inspection in most cases. This is in stark contrast to traditional destructive testing procedures which render the part/structure unusable after testing. As a result, the NDI approach is especially useful for periodic maintenance/inspection of structures followed by deploying these back into service. This is true across a variety of industry sectors such as aerospace, oil & gas, transportation, construction, power generation, etc. A representative example is the use of NDI techniques for the periodic inspection of aircraft structures as mandated by the Federal Aviation Administration (FAA) [1, 2]. More broadly, NDI could be conducted at the production, in-service, or forensic stages. Production inspections are those conducted during or at the end of a manufacturing process of a product; the objective here is to detect discontinuities or defects that this internal or external to the product surface as well as 1D, 2D or 3D in nature; for large batch-size production, usually a smaller sampling of parts is inspected. In-service inspections are those conducted during the routine maintenance or overhaul of a product, a good example being the FAA-mandated inspections of aerospace structures mentioned earlier. Over the years, some of the most commonly seen aerospace structural failures were initiated and propagated via fatigue loading, in which case, crack initiations typically originate from the outer surface or from a material discontinuity. Finally, forensic inspections are those conducted after part/system failure (often at a catastrophic level) to ascertain the causes and effects of defects on the aforementioned failure. It is to be noted that conceptually, NDI techniques are not just restricted to inspecting non-biological structures, but to biological entities as well – for instance, x-rays of teeth obtained at a dentist [3], ultrasound images for prenatal care [4], etc.

For the majority of non-biological NDI testing, especially for typical industrial uses, the American Society for Nondestructive Testing (ASNT) is the international standardization society for NDI professionals which sets standards for qualification and certification of trained personnel. Of course, certain high-risk and specialized sectors (*e.g.,* nuclear) have additional requirements for qualifying procedures and personnel. To keep abreast of the latest educational standards in the field, this specific NDI course that was developed at TAMU utilizes technical material directly from the Nondestructive Testing & Evaluation (NDT&E) Education website [5] which is meant to provide a comprehensive source of information for NDI technical education. This website was created in the 2000's by NDI professionals and educators from Iowa State University and five regional community colleges. It is currently maintained with funding from the American Society of Nondestructive Testing (ASNT) and the National Science Foundation (NSF) Advanced Technological Education (ATE) Program.

Within the College of Engineering at TAMU, the MMET program houses an ABET-accredited 4-year engineering technology degree that imparts a hands-on approach to education, whereby ~80% of the courses are accompanied by complementing laboratory sessions. The majority of these labs have been developed over the years with direct input and assistance from industry stakeholders that comprise the industrial advisory board of the program, and who meet every year to discuss curricula, among other things; it is worthwhile to note that most of these industry personnel, who are mostly upper-level managers are past graduates of the program themselves. Being in the vicinity of the major aerospace and energy industries in Texas, these industry partners and other technical workforce recruiters have raised a specific recurring concern over the years, that the graduating senior undergraduates, who essentially constitute the incoming regional/national workforce or are graduate degree pursuers, do not exhibit the necessary and pragmatic interdisciplinary knowledge/skills in metrology and inspection. Similar feedback was also echoed by both small/large regional manufacturing and energy industry partners that predominantly hire such students. This course and lab development in NDI (and its eventual refinements) was thus a direct response to address this unmet need of generating graduates who could become a regional workforce well-rooted in metrology and inspection technologies, and specifically NDI that is all the more relevant to the regional aerospace and energy industry needs.

Course Structure & Complementing Lab Activities

Having its origins to directly address an unmet regional industry need, this course and its complementing laboratory activities is the only one of its kind on the university campus that is focused on NDI. It is currently structured within the B.S. degree program as a senior-level core/required course named MMET 402 - Inspection Methods & Procedures. It is offered every semester as a 3-credit course (which includes weekly lectures and labs) that students typically take during the final year of their degree program journey. The course pre-requisites include knowledge in manufacturing and materials at the appropriate needed level. Typically having an enrollment of 60-90 students each semester, the lab sections are broken down into groups of ~16 so that each student has the opportunity to be directly/physically involved in each lab exercise. The course is described as an introduction to commonly used nondestructive testing (NDT) methods and procedures for flaw detection in materials and structures including visual, liquid penetrant, magnetic particle, eddy current, ultrasonic, and radiographic technologies. Consequently, the course learning outcomes aim to enable students to be able to describe the principles and operating procedures of the most commonly used industrial non-destructive inspection technologies along with their applications and limitations. Additionally, the course is also intended to enable them to able to determine the safety distance from a radiation source and the types of radiation safety devices required by safety regulations, in the context of NDI techniques that utilize radiation sources.

From a course lecture structure standpoint, the class lectures predominantly focus on the selected core NDI techniques that are listed below:

- Visual Testing (VT)
- Liquid Penetrant Testing (PT)
- Magnetic Particle Testing (MT)
- Eddy Current Testing (ET)
- Ultrasonic Testing (UT)
    - Conventional (UT)
    - Phased Array (PA)
    - Time of Flight Diffraction (TOFD)
    - Total Focusing method (TFM)
- Radiographic Testing (RT)
    - Film-based Radiography (RT)
    - Computed Radiography (CR)

It should be noted that these specific methods were selected in conjunction with discussions and feedback from the industrial advisory board members who are stakeholders of the degree program, besides making sure to cover the most common and relevant NDI technologies currently in use. For each of the techniques used, the lecture covers the basic physical/chemical principles employed for leveraging each NDI approach, the unique configurations and features of the equipment/supplies used to detect defects, the software and hardware used for detection/recording, the data acquisition rates/equipment needed, and of course numerous examples/illustrations showcasing actual industrial case studies. Especially emphasized are the limits and limitations of each technique, along with tricks of the trade and rules of thumb that have become 'standard' over the years and catered to each distinct industry sector. Considering the complementing laboratory activities, these closely follow the lecture schedule such that the lab activities happen immediately after the students have been introduced to a specific NDI technique. It should be noted that based on the NDI technique used, each lab activity requires very specific personal protective equipment (PPE); for instance, x-ray related activities vs. liquid penetrant testing activities. Over the years, the lab activities for this course have been standardized to a total of 10 standalone lab sessions as detailed in the table below.

Table 1. Major Class Lecture Topics and Complementing Lab Exercises

Major Class Lecture Topics	Lab Exercises
Visual Testing (VT)	(No Lab)
Liquid Penetrant Testing (PT)	Lab #1 Conducting dye penetrant testing (PT)
Magnetic Particle Testing - Practices (MT)	Lab #2 Conducting magnetic particle testing (MT)
Eddy Current Testing - Theory & Practices (ET)	Lab #3 Conducting eddy current testing (ET)
Ultrasonic Testing - Theory and Practices (UT)	Lab #4 Calibration + Performing straight beam velocity (IIW block) & DAC calibrations (NAVSHIPS) + Practicing on a step block and a plastic block (UT)
Ultrasonic Testing - Transducers (UT)	Lab #5 Conducting angle beam calibration using IIW block + Practicing on a PA assessment block + Weld Inspection + Performing inspection on a flawed sample (UT)
Ultrasonic Testing - Phased Array (PA)	Lab #6 Continuing exercise on flawed samples using angle beams + Getting familiar with ESBeamTool software (UT)
Ultrasonic Testing - TOFD	Lab #7 Getting familiar with the PA flaw detector + Using ESBeamTool for PA simulation + Conducting exercises on a PA assessment block (PA)
Radiographic Testing - Theory and Practices (RT)	Lab #8 Conducting exercises on flawed samples using Omniscan (PA)
Radiographic Testing - Image Quality (RT)	Lab #9 Radiographic Safety + Getting familiar with the personal radiation safety equipment/devices + Introduction to CR system + Learning image processing with VMI's STARRVIEW software (CR)
Computed Radiography (CR)	Lab #10 Producing X-ray radiographs of low density/thin object with CR system + Conducting image processing (CR) + Radiograph Interpretation
Radiograph Generation Process	(No Lab)

It is also worth noting that the majority of the lab equipment that are utilized have been generously donated by regional industry stakeholders, which has the added advantage of students being familiar with and being trained on NDI equipment used by the donating companies themselves, thereby making the graduates of the program good candidates to be hired at those specific institutions themselves. Over the years, the program/lab has added additional training units for each NDI technique so as to have ample equipment to match higher student enrollment numbers. A representative listing of such equipment include liquid penetrant spray, table-top magnetizer and demagnetizer, magnetizing yokes/probes, ultraviolet lights, Olympus Nortec 500D and Nortec 600D eddy current flaw detectors [6], Olympus Epoch ultrasonic flaw detectors, GE Phasor XS phased array ultrasonic flaw detectors, Olympus Omniscan MX phased array ultrasonic flaw detectors [7], Lorad 160 KV X-Ray tubes, X-Ray cabinets, VMI computed radiography systems (including laser scanners and workstations), and related hardware and software for all of the NDI test setups. As a reference, representative images of the above-mentioned equipment in the lab are shown below.

Figure 1. X-Ray tube/cabinet (left) & VMI laser scanner with image processing software (right)

Figure 2. Olympus Epoch ultrasonic flaw detector (left), Olympus Omniscan MX phased array ultrasonic flaw detector (center) & GE Phasor XS phased array ultrasonic flaw detector (right)

Figure 3. Olympus Nortec 500D (left) & Nortec 600D (right) eddy current flaw detectors

Representative Laboratory Exercises

For a better understanding of the type of laboratory exercises developed, a brief description of two representative laboratory tasks is given below.

The first involves sorting metals by leveraging eddy current technology (ET). Eddy current is currently one of the most effective and widely used methods for the sorting of scrap metals, especially separating ferrous metals (*i.e.*, steels or iron-based materials) from non-ferrous metals for the purposes of recycling/reuse. It can also be utilized to separate among the non-ferrous metals. The three parameters that affect the interaction between an eddy current system and a material (which produces different impedance outcome at equilibrium) are magnetic permeability and electric conductivity of the material, and current (or magnetic field) frequency of the ET probe. Because ferrous metals are basically magnetic and non-ferrous non-magnetic, they will have quite different impedance value for a given probe frequency at equilibrium. Similarly, due to the significantly large differences in electric conductivity, the sorting among non-ferrous metals can also be accomplished by the eddy current method. The image below shows how the ET probe is used to sort out 9 different metals including low carbon steel, tool steel, stainless steel, nickel, titanium, copper, bronze, and different aluminum alloys.

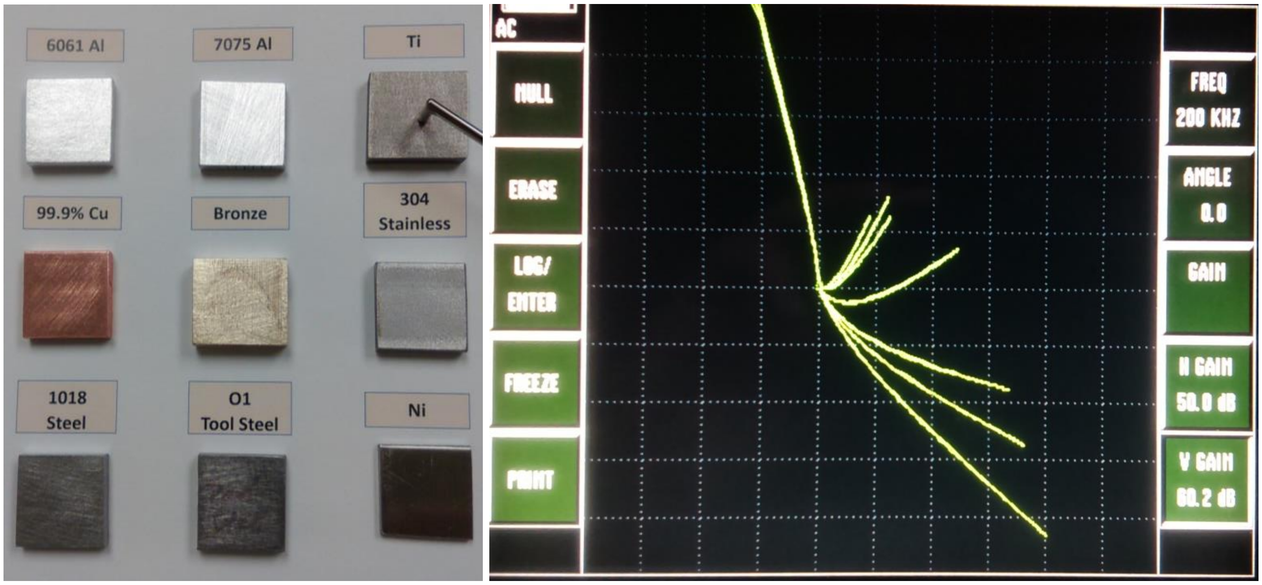

Figure 4. NDI lab task that involves the sorting of various common scrap metals using eddy current

The second representative lab task involves finding the effect of defect orientation relative to a sound beam using ultrasonic technology. For this, a plastic block with embedded pennies at specific orientations was employed for ultrasonic testing. The differences in the resulting amplitude readings of the ultrasonic probe when encountering each penny was used to detect its orientation (see figure).

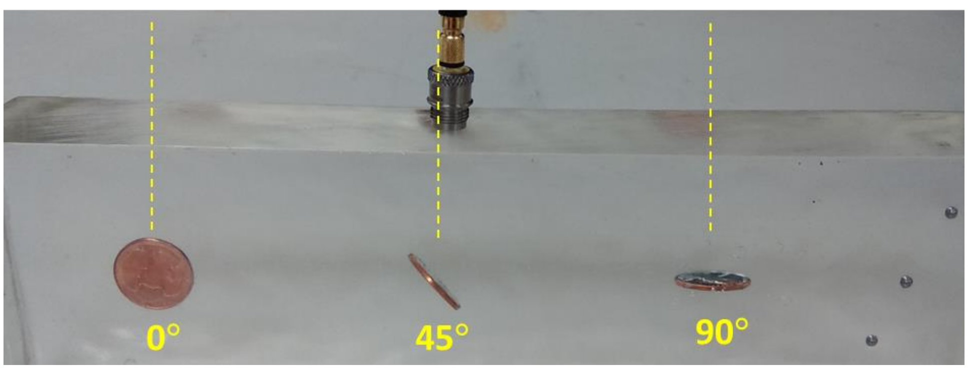

Figure 5. NDI lab task that utilizes ultrasonic probing to detect 'flaw' orientation

Course Reception & Path to Certification

This course has been offered as part of the B.S. degree program for over a decade, all the while garnering consistently positive feedback from the students. The complementing lab activities, which are very relevant, hands-on, and 'interesting' to do/observe is believed to be one of the main reasons for such consistently positive feedback, which remained unchanged even through the changing of instructors, teaching assistants and even the COVID-19 period. Another supporting reason for such positive reception (as gathered from course feedback over the years) is the direct relevancy of the NDI techniques used to real world applications, and especially to the regional aerospace and oil & gas industry corridors nearby – in fact, a significant portion of the students had been exposed to some form of such NDI techniques already as part of their internships in these very same industry sectors. A sampling of the comments received that highlight the course content/relevance follow:

- "Very clearly organized. I appreciated the overview of the course at the beginning of each new testing method."
- "I enjoyed this class. Very interesting material."
- "I really enjoyed this course."
- "I will do this as part of my job and feel very well prepared for it. This is a … course … that I have looked forward to."
- "I'm walking away feeling like I have basic knowledge on all that we learned."
- "Learning each NDT method was extremely helpful."

It is also worth noting that both written and lab performance as well as the course grades obtained by students were generally above the average course grades obtained for courses at the 400-level within the same B.S. program – this highlights the students' interest, motivation, and overall better performance in this very hands-on course. As an illustration, the exam, lab and course performance of a representative semester (within the last 5 years) is tabulated below; note that the typical course enrollment is ~60-90. It can be seen that the students performed especially well in the laboratory component of the course, while they generally performed in an above average manner for the exam (and overall) when compared to courses at this level in the B.S. program. It is also worth noting that for ABET accreditation and internal college/university-level assessment purposes, the course learning outcomes were defined to be met if at least 70% of the students score above a 70% grade – this was of course very comfortably achieved in the representative semester highlighted below, as well as all in all of the semester that the course has been offered.

Table 2. Exam, Lab & Course Performance of a Representative Semester

Exam grade	% of students within this grade (average of 3 exams)	Lab grade	% of students within this grade (average of 10 labs)	Course grade	% of students within this grade
≥90%	19.80%	≥90%	96.20%	≥90%	41.50%
80-89%	35.80%	80-89%	3.80%	80-89%	41.50%
70-79%	27.40%	70-79%	none	70-79%	15.10%
<70%	16.90%	<70%	none	<70%	1.90%

Path to Professional Certification

Though not a course catered to a technician career, there is an added benefit of passing this course/lab as part of the 4-year ABET-accredited B.S. degree – this involves accruing hours toward an NDT Level-II certification. NDT personnel certification is conducted by the American Society for Nondestructive Testing (ASNT) standardization organization, with additional certifications at the corporate level conducted by the particular companies themselves. In general there are four requirements toward certification, which include education, training, testing, and work experience. The table below highlights the training hours requirement for NDT Level II Certification and how the course contributes toward this requirement. It is worth noting that such exposure/experience is especially 'attractive' to employers from the regional aerospace and oil & gas industry sectors who heavily use such techniques in their day-to-day operations.

Table 3. Training Hours Requirement for NDT Level II Certification

NDT Method	Training Hours
Liquid Penetrant (PT)	12
Magnetic Particle (MT)	20
Eddy Current (ET)	40
Ultrasound – Conventional (UT)	80
Ultrasound – Phased Array (PA)	40
Ultrasound – Time of Flight Diffraction (TOFD)	40
Radiography – Film-Based (RT)	80
Radiography – Computed Radiography (CR)	40
Total	352
MMET 402 (Lecture + Lab)	46

Other Programs Showcasing the NDI Laboratory

Besides for the course use as part of the B.S. degree, the NDI laboratory is frequently visited by prospective university students, minors (as part of outreach programs), and during industry personnel visits at the department and college levels. Visitors are always impressed by the demonstrations conducted, as well as the fact that the majority of the equipment was donated, besides its direct relevance to the regional industry sectors. One added benefit of having industry visitors is that these interactions have in multiple instances resulted in sponsored industry research projects with the faculty. A representative instance of utilizing this lab is the annual NDI workshop conducted within the lab as part of a National Science Foundation (NSF) Research Experiences for Undergraduates (REU) Site on Interdisciplinary Research Experiences in Metrology & Inspection; this has been offered since 2017. The REU site goals are to enhance the knowledge and skill-level of undergraduates through empowering, hands-on and interdisciplinary research experiences in metrology and non-destructive inspection (NDI) technologies. As part of this program, each year, 10-12 undergraduates who are external to the university spend ~10 summer weeks on campus engaged in a research project; they take part in the aforementioned NDI workshop during this time. As a result, the site impact is to create empowered future researchers and a workforce well-rooted in metrology/inspection techniques, and to motivate them to pursue advanced study and STEM careers. Representative images from a recent offering are shown below that show these students taking part in various NDI laboratory exercises.

Figure 6. NSF-REU students at the NDI lab using the magnetizer and ultrasonic flaw sensor

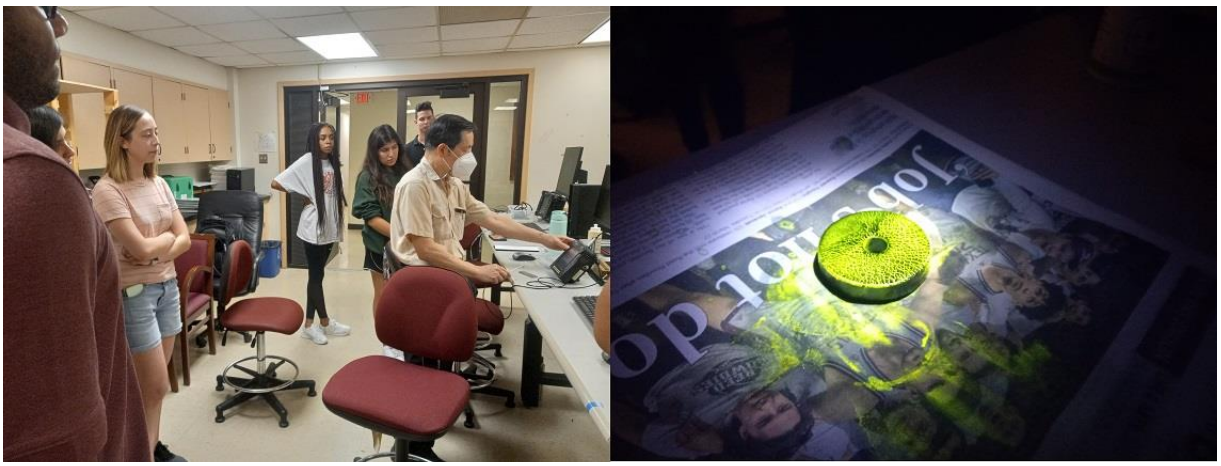

Figure 7. NSF-REU students during NDI lab exercises including the dye penetrant method

Summary and Conclusions

In summary, this paper describes the curricular developments made as part of an undergraduate-level non-destructive inspection (NDI) course and its complementing labs, to better prepare undergraduates for the regional workforce needs. Guided by industry stakeholder advice and donations, a number of common and relevant NDI techniques were selected for teaching to the students; this included technical material from a current ASNT/NSF-funded online resource, as well as complementing laboratory exercises that provided a hands-on education to the students. Student feedback has been consistently positive over the years, with lab performance being especially exemplary. Further, passing the course as part of the B.S. degree program also helped accrue hours for a professional level-II NDT certification. Besides course use, this NDI lab has also found frequent utilization for student/industry visitors, outreach programs and undergraduate research activities. Altogether, the NDI course and lab together is serving to empower future researchers and a workforce well-rooted in non-destructive inspection (NDI) technologies.

References

1. Federal Aviation Administration (FAA), 2012, Maintenance Review Boards, Maintenance Type Boards, and OEM/TCH Recommended Maintenance Procedures, Advisory Circular 121-22C.
2. Federal Aviation Administration (FAA), 2008, Chapter 8. Inspection Fundamentals - Aviation Maintenance Technician Handbook, AFS-600, pp. 8–15, FAA-H-8083-30.
3. Erdelyi, R.A., Duma, V.F., Sinescu, C., Dobre, G.M., Bradu, A., Podoleanu, A., 2020, "Dental Diagnosis & Treatment Assessments: Between X-rays Radiography & Optical Coherence Tomography, Oct 28;13(21):4825.
4. University of Michigan Health - C.S. Mott Children's Hospital, Prenatal Diagnostic Tests, URL: https://www.mottchildren.org/conditions-treatments/peds-fetal-medicine/prenatal-diagnostic-tests.
5. Iowa State University - Nondestructive Testing & Evaluation (NDT&E) Education, URL: https://www.nde-ed.org/.
6. Olympus - NORTEC 600 Eddy Current Flaw Detector, URL: https://www.olympus-ims.com/en/nortec600/.
7. Olympus - Omniscan Phased Array Ultrasonic Flaw Detectors, https://www.olympus-ims.com/en/omniscan-mx2/.