Course in Eddy Current Nondestructive Testing to Pilot New Online Graduate Certificate in NDT

by Nicola Bowler*

Introduction

This fall, I am teaching a course titled "Eddy Current Nondestructive Evaluation" at Iowa State University. I first presented the course in a classroom on the Iowa State campus in the fall of 2007. In fall 2008, my classroom extends well beyond Ames to include students from across the state and nation, courtesy of the World Wide Web.

Funded in part by a grant from the American Society for Nondestructive Testing, the course is aimed at students and practitioners who wish to improve their understanding of a technique that is often perceived to be one of the more conceptually difficult methods in NDT (X-rays travel in a straight line, after all; eddy currents don't). I seek to teach a fundamental understanding of how eddy currents are generated in a test piece, what a probe measures, and how these data should be interpreted when measuring material properties or when detecting and characterizing discontinuities. The primary course objective is to equip the students with knowledge that enables them to go beyond the procedure of routine testing. Appreciation of the principles on which eddy current NDT is founded, taught in this course, might perhaps allow a practitioner to optimize a particular NDT application by judicious choice of probe type and operating frequency or, in another setting, equip a research student with the required knowledge to minimize uncertainties in a quantitative eddy current measurement for model validation.

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Background

In a climate in which many companies encourage continuing professional development of their workforce, online education is an attractive means by which educational opportunities can be made available to working engineers who don't have the luxury of leaving the workplace to sit in a college classroom. Iowa State's Engineering Distance Education group is one of the oldest and most experienced deliverers of distance learning opportunities in the nation, as well as a pioneer in online education for working professionals. Classes and lectures are delivered in real time via streaming video, after which they are accessible anytime from online archives. Other online tools include a discussion board upon which students can post questions for the instructor or other students, and a personal gradebook that allows students to keep abreast of their progress. Lecture slides, notes made by the instructor during class time and supplementary materials are all made available online.

Content

The course content follows closely the contents of a textbook that is being specifically written to accompany it (*Eddy Current Nondestructive Testing*, by N. Bowler and J.R. Bowler). Fundamental to eddy current NDT is the coupling of the magnetic field produced by the eddy current coil and the test piece in which eddy currents are induced. This coupling is rooted in Faraday's law of electromagnetic induction, expressed mathematically as one of Maxwell's four equations of electromagnetism. While students are not expected to perform complicated manipulations of Maxwell's equations, an appreciation of the coupling between the electric and magnetic fields as represented by these equations will be taught. For this reason, the course begins with a review of the necessary mathematics: complex numbers, vectors and vector calculus. Prior familiarity with these tools is helpful but not essential.

The signal of an eddy current probe, its impedance, is initially discussed in terms of elementary circuit theory, and later in terms of the electromagnetic field that couples the probe and the part. The circuit theory approach is useful for understanding some characteristics of real probes (such as the limitation of the operating frequency range due to probe resonance) whereas the field based approach allows modeling of the coil impedance due to various test pieces and discontinuities. For example, the formula for electromagnetic skin depth is derived from first principles, revealing the conditions under which this formula is

* Materials Science and Engineering, Electrical and Computer Engineering, Center for Nondestructive Evaluation, Iowa State University, 279 ASC II, 1915 Scholl Rd., Ames, IA 50011-3042; (515) 294-5370; fax (515) 294-7771; e-mail <nbowler@iastate.edu>.

a good (or bad) approximation of the penetration depth of the eddy current density. Moving on from this basic understanding of probe behavior, the purpose of various eddy current probe types (absolute, differential and driver pick-up, and modifications of these), by the use of ferrite cores for example, is discussed. In order to provide a fundamental understanding of probe responses to various discontinuities, simple models of probe impedance due to voids, inclusions and cracks are studied.

Any practitioner knows that a ferromagnetic test piece, such as iron and many of its alloys, behaves remarkably differently in its eddy current response than nonferromagnetic metal. Part of the course is devoted to ferromagnetism and its effect on eddy current NDT. Not only is the effect of a ferromagnetic test piece on the probe response discussed, but the role of ferrite cups and cores in probe design is revisited in this setting. Principles of conductivity measurement via the four-point potential drop technique are taught here due to the inability of eddy current NDT to routinely measure the conductivity of ferrous metal.

The course rounds off with an overview of several other areas of practical and academic interest. Characterization of layered systems with electromagnetic NDT is currently of great interest to the testing community, in attempts to measure surface residual stress in aircraft engine alloys and the depth of case hardening in surface hardened steels. Niche techniques such as remote field and transient eddy current NDT are covered. The role and characteristics of solid state sensors as pick-up devices especially suitable for formation of arrays for large scale testing is taught.

Finally, students taking the course at the graduate level are required to write a term paper on a topic agreed upon with the instructor, and also give a presentation to the class on the same subject. Such a paper and presentation is not required of students enrolled at a non-graduate level.

Pedagogy

Since the course is Web based, it requires a reexamination of pedagogical methods. Which tools other than traditional lectures should be employed to enhance student learning? In a campus based course, access to laboratory equipment permits experimental assignments that both motivate and reinforce classroom learning. A survey of the students that took the class in 2007 indicated that the practical component of the course was perceived to be important and useful in consolidating their learning. How to replicate this experience for distance education students?

Advances in computer based instrumentation have permitted development of a virtual eddy current instrument that interfaces with a student's PC by plugging into the USB port. The computer screen is used to mimic the screen of a conventional eddy current instrument. When packaged together with two or three probe types and a suite of purpose-made test pieces, the distance student will be able to fully benefit from the complementary learning offered by experimental assignments traditionally available only to campus based students or those with suitably equipped laboratories. A PC based virtual instrument suggests immediate and integrated model based interpretation of measured experimental data. Although this capability is not available in the present generation of the virtual instrument, model based simulations will indeed be utilized for both in-class demonstrations and for worked assignments. Like experiments, physics based computer models provide a useful tool by which key concepts may be demonstrated and explored.

According to the Sloan Consortium (2008), a nonprofit organization dedicated to monitoring and improving the quality of online education, about 20% of all US college students—nearly 3.5 million people—took at least one online course during the fall 2006 term, a 10% increase over the previous year. As options have increased with improved technologies, the numbers of working professionals taking advantage of online degree programs have increased dramatically as well. Such innovation is particularly fortuitous for the NDT community because NDT is not typically a major area of engineering study in its own right (it is offered as a minor to undergraduates at Iowa State).

Iowa State's Center for Nondestructive Evaluation (CNDE) is a National Science Foundation Industry/University Cooperative Research Center, whose core mission is to conduct industrially relevant research, including the transfer of results to industry.

In order to meet the growing need for expanded online learning opportunities in NDT, the Engineering Distance Education program and CNDE at Iowa State have partnered to develop a graduate certificate program in NDT to be offered online to industry professionals in the near future. Graduate certificates through the Engineering Distance Education program typically comprise a minimum of four courses (12 credit hours), including at least one required course in addition to electives. Besides an advanced course that surveys the principles of several NDT techniques and my own course in eddy current testing, electives for online delivery are planned to cover a range of major NDT techniques including the ultrasonic and penetrating radiation methods. A course surveying emerging topics in NDT such as probability of detection and service life prediction is also planned.

The prospect of reaching beyond the traditional classroom into the professional workplace courtesy of the World Wide Web is one that is exciting to me as an instructor. Technology makes it easy to integrate model based simulations and movies with traditional lecture materials. Electronic writing tablets that capture the in-class notes of the instructor provide a more complete record of each lecture than ever before. These tools, coupled with hands-on experience available via computer based virtual instruments, offer a well-rounded learning experience to all students whether they are on campus or on the road doing their job.

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References

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