Development of a Senior-Level Course on Maintenance and Reliability Engineering

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Abstract

The development and delivery of a new course on *Maintenance and Reliability Engineering* (MRE), for seniors and first-year graduate students in engineering, is the focus of this paper. The objective of this course is to present the fundamentals of MRE and maintenance management. Students learn the principles of various maintenance technologies as they are currently practiced by U.S. industry. The course activities include lectures, laboratory experiments, field trips, and team-based projects that are selected from different engineering disciplines. Distance education modules, with direct teacher-student interaction, are being developed. This new educational activity augments and broadens students' capability in problem solving, with an opportunity for their career enhancement.

1. Introduction

The College of Engineering at The University of Tennessee established the Maintenance and Reliability Center (MRC) in 1996, with the vision of promoting education, research, information dissemination, and industry-academia networking in the field of maintenance and reliability engineering. This industry-sponsored Center provides a unique stepping stone through its certification program for engineering majors[1]. The estimated maintenance costs in all of the U.S. industry sectors exceeds $500 billion annually. Global competitiveness, product quality, and economics of manufacturing have increased the visibility of industrial maintenance organizations. A well-planned and efficiently managed maintenance activity, the implementation of condition-based maintenance techniques, and the integration of plant maintenance and operations would enhance the chances of achieving the mission set out by the industry management[2, 3].

Introduction to Maintenance and Reliability Engineering is one of the four courses being developed as part of a National Science Foundation Combined Research Curriculum Development (NSF-CRCD) project[4]. The course provides both classroom and laboratory experience for seniors and first-year graduate students in engineering. The topics are developed in a modular form, consisting of text material, instructor material, problems, and quizzes. The following major topics have been developed:

- Overview of maintenance and reliability engineering.
- Digital signal processing (DSP) and information extraction from machinery data.

- Vibration analysis, rotating machinery condition monitoring, and case studies.
- Robotics in remote handling and maintenance.
- Lubrication oil analysis and tribology.
- Nondestructive examination (NDE) methods and applications.
- Equipment reliability, failure models, and life prediction.
- Maintenance planning, management, and performance evaluation.
- Monitoring and maintenance of process instrumentation.
- Electrical signature analysis for machinery condition monitoring.

A teaching laboratory with state-of-the-art equipment to demonstrate the technology fundamentals and for hands-on experience compliments the classroom activities. Web-based and synchronous distance education delivery modes are also being developed. The Internet facility is used for student group discussions and for posting course material and other information relevant to the course. This introductory course also meets the need for the certification requirements and engineering experience needed in the rapidly growing area of maintenance and reliability engineering. Interaction among team members, communication with industry experts, and the use of electronic information systems are strongly emphasized in the course.

2. Description of the Course

This section provides an outline of the course and the expectations of student learning. The course materials are also drawn from recent research and development in maintenance technologies. The choice of topics described may vary from one semester to another and depends on the mix of students from various engineering disciplines. One of the objectives of the course is to prepare students to place themselves well professionally, by providing the fundamentals of maintenance and reliability engineering and maintenance management. The following is a summary of the course material.

- The overview of maintenance and reliability engineering describes the scope of industrial maintenance, provides a summary of condition-based maintenance technologies, and definitions of terminology.

- Information extraction from machinery measurements using digital signal processing (DSP) is presented during two class modules. This includes instrumentation, data acquisition, signal conditioning, time-domain and frequency-domain analysis of machinery data, and demonstration of a typical data acquisition and analysis system. Case studies of machinery monitoring are discussed. Hands-on activity by students is encouraged to familiarize them with sensors and data analysis.

- Vibration analysis is the most extensively used technology for condition monitoring of rotating machinery. Two course modules are devoted to this topic. The subtopics include: vibration and its causes, classification using frequency bands, instrumentation for vibration measurement, description of a typical vibration monitoring system, vibration modeling of a second-order system, vibration signatures, data trending and alarming methods. Several case studies of vibration

monitoring are presented. These include: turbine imbalance, pump misalignment, belt-drive looseness, boiler feedwater pump anti-friction bearing monitoring, pump journal bearing monitoring, rolling mill gearbox problem, transient vibration analysis, and definition of rolling element bearing defect frequencies.

- Robotics and remote handling is of importance in maintenance in hazardous situations and hard-to-access environment. Principles of robot systems and remote handling, applications in industrial maintenance, and the use of virtual reality in periodic and corrective maintenance are also presented.

- With the advancement of equipment for oil analysis, machinery lubrication oil monitoring is becoming economical and less labor intensive. Lubrication oil analysis includes the detection and quantification of chemical composition, contaminants, and wear particles in oil. This technology is often referred to as *tribology*. This module discusses the scope of tribology, classification of lube oil test methods, oil contamination and wear particle analysis, and case studies of industrial applications. This module includes the demonstration of equipment for oil analysis and viscosity measurement.

- Nondestructive examination (NDE) methods are used extensively in several industries in order to verify the integrity of structures and systems. NDE techniques are also used for periodic examination of tubing in heat exchangers, fossil plant boilers, and nuclear plant steam generators. This learning module includes the following topics: overview of NDE, typical applications, and standards; visual examination, penetrant testing, and magnetic particle testing; ultrasonic testing; eddy current testing; radiographic testing; thermographic testing; acoustic emission testing. Several applications and demonstrations are presented.

- The performance of manufacturing facilities are often evaluated using the reliability, availability, maintainability, and safety (RAMS) of equipment. This module provides an overview of reliability and failure models and examples illustrating their applications. The ultimate goal of an advanced maintenance system is to be able to predict the remaining useful life of (critical) plant equipment. Often referred to as equipment prognosis, this module describes the basic approach for trending machinery performance data and performing life prediction or prediction of time-to-alarm. Case studies of applications to rotating machinery and heat exchangers are presented.

- For the successful performance of a maintenance organization it is necessary to follow the maintenance activities in the order – maintenance planning, management, and its performance evaluation. These principles are discussed in this module, along with methods for estimating optimal periodic maintenance interval and replacement.

- The key to the success of condition-based maintenance is the acquisition of accurate measurements from both process and machinery monitoring sensors. This module discusses the following issues: principles of temperature, pressure, and flow

transmitters; principles of motor current, voltage, and flux measurements; scope and objectives of instrument surveillance and calibration; validation of plant sensors; smart sensors; and case studies.

- Electrical signatures from motors coupled to plant equipment provide excellent indication of the status of the motor and the driven system. This module discusses the principle of motor as a transducer, and provides an introduction to machinery monitoring using motor current, motor power, and flux signatures. Laboratory experiments and case studies of applications to industrial systems are part of this module.

Some of the learning modules are presented by industry experts who bring their engineering experience and knowledge to the classroom. The students have an opportunity to visit a large manufacturing facility as part of the course activities. The facility is chosen with the intention of demonstrating the importance of maintenance for a large manufacturing plant. An example of one-semester course schedule is shown in Figure 1. The duration of each weekly meeting is 150 minutes.

3. Course Delivery

The course is developed in a modular form, with each module focusing on a topic in maintenance and reliability engineering as described in Section 2. Each topic consists of text material, instructor material, problems, and a quiz. The course material is available to the students on a password-protected homepage in advance of the class period. The students are encouraged to review the material before the class. The homepage called the *CourseInfo* has several features, including student group discussion facility, chat room, bulletin board, and features for use by the instructor. Homework assignments and other relevant information pertaining to the course are posted periodically.

The first presentation of the course was videotaped in a studio and consisted of twelve modules. The video also consists of clips from experimental demonstrations and student presentations. A synchronous delivery system for distance students is being developed and uses the *Centra Symposium* software[5]. This provides a direct link for the students with the instructor through their computer stations. The *Symposium* software allows on-line demonstration of engineering problem solving, voice communication, and a whiteboard for on-screen handwritten response by the instructor.

4. Course Features and Learning Outcomes

The learning outcomes of the course also contribute to the various ABET-specified outcomes. This is a course with interdisciplinary features. The design aspect and independent learning are emphasized in student projects. The students are encouraged to communicate with industry experts and exploit the Internet communication facilities for gathering needed information. The following are some of the unique features of the course.

- The course contributes to the ability to apply knowledge of basic sciences and engineering.
- The course strongly emphasizes a student project. The project duration is long enough for the students to perform a detailed study of a topic that involves design and

Introduction to Maintenance and Reliability Engineering (1999)

DATE	TOPIC
January 14	Overview of maintenance and reliability; current issues.
January 21	Signal processing and information extraction from machinery measurements.
January 28	Examples and applications of signal processing. Demonstration of data acquisition and analysis.
February 4	Principles of vibration analysis; instrumentation for vibration measurement.
February 11	Condition monitoring of rotating machinery using vibration analysis. Case studies and demonstration.
February 18	Lubrication oil analysis and tribology. Case studies and laboratory demonstration.
February 25	Site visit to ALCOA Tennessee Rolling Mill Plant. Review of maintenance practice at the facility.
March 4	Reliability engineering, failure models and life prediction.
March 11	Mid-term examination. Review of student projects.
March 25	Nondestructive examination (NDE) methods and applications. Demonstration of key technologies.
April 1	Maintenance planning, management and evaluating maintenance performance.
April 8	Monitoring and maintenance of process instruments. Temperature, pressure, flow, electric current, voltage, magnetic flux and others.
April 15	Electrical signature analysis for machinery condition monitoring. Demonstration and case studies.
April 22	Presentation of student projects.
April 29	Presentation of student projects. Course review
May 6	Final Examination.

Figure 1. Course topics and schedule during the Spring 1999 semester. Each weekly meeting is of 150 minutes duration.

development of a prototype device or computer software with relevance to MRE topics.

- The topics covered in the course are multi-disciplinary in nature, and are further enhanced by student projects and visit to a manufacturing facility.
- The engineering and professional responsibility of developing and implementing a high quality and economically viable plant maintenance system is emphasized.
- Students have the opportunity to develop their communication skills, both written and oral. They are encouraged to communicate through different media and form discussion groups as part of their project activities.
- The course emphasizes the broad education necessary to understand the impact of solutions to industrial maintenance and reliability problems, which are global in nature. Students entering into profession in this area realize the need for continuing education related to emerging technologies and practices. Thus, life-long learning is not an option.
- Contemporary issues and recent technological developments are addressed throughout the course. The students are encouraged to understand the importance of the economics of change and cost-benefit issues.
- Modern engineering tools utilized in the course include a laboratory facility, software systems for data acquisition and analysis, sensors and special devices. The students have the opportunity for hands-on experience in the laboratory.

The course is designed for seniors and first-year graduate students in engineering. The prerequisite is senior standing (and the consent of the instructor). This is one of the courses required for certification by the Maintenance and Reliability Center at The University of Tennessee. The students receive their degrees in their respective majors.

One of the highlights of the course that contributed to the learning experience of the students is their involvement in an extensive project during the semester. The class is divided into smaller groups and each group is expected to work on a project of current interest to industry. The following are examples of student projects developed during the Spring 1999 semester.

- Maintenance procedures at major U.S. airlines.
- Maintenance practices at three major automotive manufacturing facilities.
- Application of reliability-based maintenance principles at the Knoxville Utilities Board Kuwahee wastewater treatment plant.
- Development of a virtual vibration experiment.
- Aircraft maintenance display user interface model.

All the reports and presentations are available in electronic form.

A teaching laboratory has been developed and is being used in conjunction with classroom lectures. The laboratory consists of the following experimental modules.

- Machine fault simulation and vibration monitoring, including a laser alignment device.
- Induction motor testing system with multiple measurement points consisting of accelerometers, motor current probes, flux coils, thermocouples, and load measurements.
- Small-scale AC motor-generator system for studying electrical measurements.
- A tabletop variable speed DC motor system with imposed shaft imbalance.
- Eddy current test system to illustrate the principle and applications of eddy current using standard specimens.
- Ultrasonic test system to illustrate the principle and applications of ultrasonic testing.
- Lube oil analysis system with a digital viscometer. Both contamination and wear particle analysis can be performed.

The various devices are interfaced with personal computers for data acquisition and analysis. Some pieces of equipment are donated by the industrial members of the Maintenance and Reliability Center.

5. Concluding Remarks

The development and delivery of a new course on *Maintenance and Reliability Engineering* is presented and some of its highlights are indicated. In a course of this topical content it is necessary to realize that the student background is not uniform. The course content should be varied from year-to-year and the course development must include modules in excess of what is necessary for a one-semester course. The topics, then, may be chosen from a larger pool of material each year. The instructor must encourage students to acquire information through the use of technology web sites that include professional societies, industry, user groups, and technical journals and magazines.

The course delivery must include as many examples and case studies as possible in order to illustrate the principles. The instructor needs to develop a procedure to verify that the students carefully review the course material and the handouts. Weekly quizzes and weekly updates on student projects would provide the instructor with continuous feedback on student progress. It is the author's experience that direct discussion with the students is the best means of receiving feedback on the content and quality of the course.

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