Development of a Maintenance Engineering Laboratory

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Abstract
The paper outlines the development of a senior-level laboratory for demonstration and hands-on activities related to various maintenance technologies. This laboratory has been developed as part of a course entitled ***Introduction to Maintenance Engineering***, which is designed for seniors and first-year graduate students in engineering. The course and the accompanying laboratory were developed at The University of Tennessee under an NSF-CRCD grant. Students learn the principles of various maintenance technologies as they are practiced by U.S. industry. Six laboratory modules, spanning the important maintenance technologies, are currently available. The scope of the Laboratory has been enhanced by providing Internet access to machinery data.

1. Introduction
The University of Tennessee, Knoxville has a well-established certificate program in *Maintenance and Reliability Engineering.* This program is designed primarily for undergraduate students in engineering. In addition, a graduate certificate program in *Maintenance and Reliability Engineering* is available for both on-campus and distant students[3]. The course entitled ***Introduction to Maintenance Engineering***[1] is a required course for both certificate programs. This course, along with three others, were developed under an NSF-CRCD grant. The course is taught for seniors and first-year graduate students in engineering, and is designed in a modular fashion with each module describing a specific topic in maintenance engineering. The course activities include team projects, and cyber-linked student projects[2] with student teams in France and Brazil. This independent study component provides experience in team-based activity and coordinating and carrying out project goals when the teams are separated by large distances.

In order to compliment the classroom activities, a Maintenance Engineering Laboratory was developed under the NSF-CRCD grant. This self-contained teaching laboratory helps to improve the infrastructure for both education and research. About 60% of the laboratory equipment was donated by members of the Maintenance and Reliability Center. The following six laboratory modules are currently available. All the modules, except the motor test laboratory, are designed as tabletop experiments.

- Machinery vibration monitoring system (including a precision laser alignment system).
- A variable speed motor drive for monitoring transient operation and a tabletop motor-generator system to study electrical measurements.
- Full-scope motor test laboratory, complete with vibration, electrical, and temperature measurements.
- Lubrication oil analysis module.
- Eddy current test module.
- Ultrasonic test module.

A brief description of the experimental modules is given in the following sections.

2. Machinery Vibration Monitoring

The objective of this laboratory module is to demonstrate the monitoring of vibration characteristics of rotating machinery under various degradation conditions. These include shaft imbalance, misalignment between two pieces of rotating equipment, bent shaft, bearing faults, and gearbox anomalies. The system consists of a one-horsepower induction motor, which is connected to a shaft with variable weights and a provision to change the load on the motor. The shaft is connected to a gearbox through a belt drive. The system is supplied by SpectraQuest, and has the capability to vary the motor speed.

The vibration is measured by six accelerometers, three on each bearing (vertical, horizontal, and axial). The sensors are connected to a power supply; the signals are amplified and filtered as needed, and routed to a patch panel. The patch panel interfaces with an analog-to-digital card installed in the PC. The data acquisition is performed using the LabView™ software. The module provides Internet access to machinery data using the concept of *Virtual Vibrations Laboratory*. This enables the user to acquire data at any desired sampling rate and review time and frequency display of vibration signals. In addition, the LabView Internet Toolkit allows the system to be viewed and controlled through the web.

A complete manual, that describes the principles of vibration monitoring, examples of diagnosing machinery faults, and student exercises, is available to the students. A typical example of the frequency spectrum from an accelerometer signal mounted on one of the bearings is shown in Figure 1. The figure shows a high-energy component due to a bearing fault at a frequency of about 523 Hz.

3. Motor Test Laboratory

The motor test laboratory was developed to study the degradation of induction motors under different accelerated aging conditions. The original experiments included thermal aging of bearings, aging of bearings due to electrical discharge machining or fluting, and thermal aging of stator windings. The current objective of this laboratory is to familiarize the student or user with induction motor principles that include basic operational concepts, fault and failure modes, and the detection of faults using both vibration and electrical signals. A schematic of the motor test laboratory is shown in Figure 2.

A 5-HP induction motor is coupled to a dynamometer, which is used for loading the motor. The induction machine is a 3-phase, 4-pole, 1,800-RPM no-load speed, induction motor, with a full-load maximum slip of 5%. The following measurements are available for the analysis of mechanical and electrical faults in the motor.

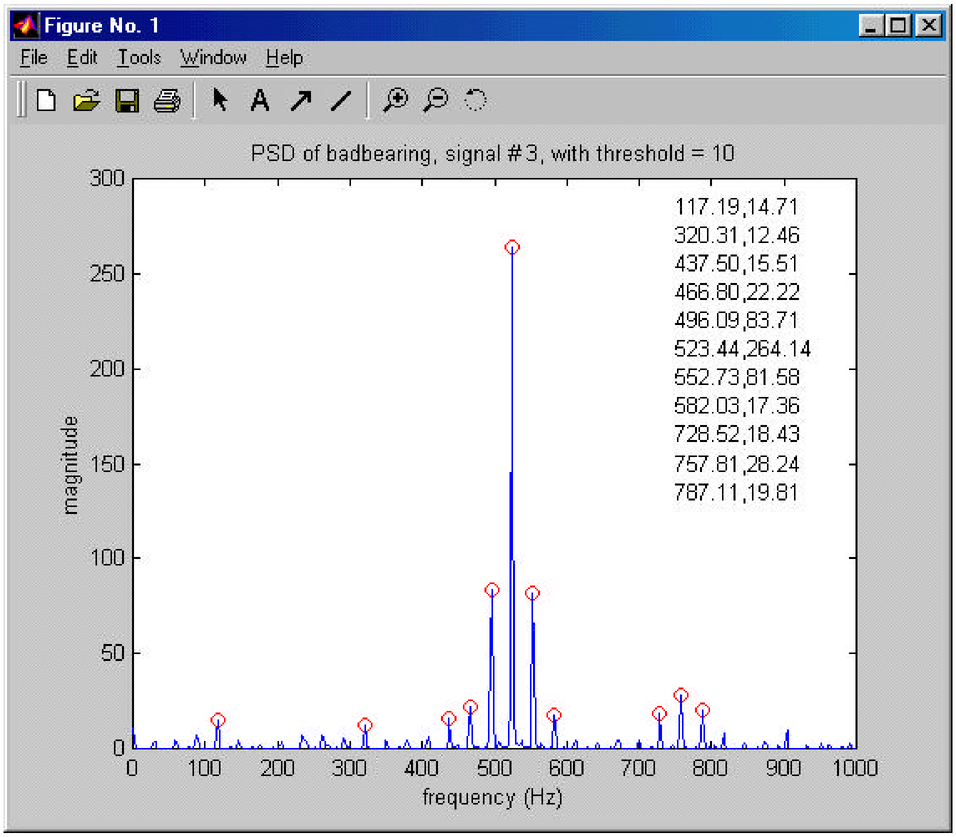

Figure 1. A typical frequency spectrum of an accelerometer signal, indicating a bearing fault, with a high-energy frequency component at 523 Hz and its side bands.

- Accelerometers on motor bearings.
- 3-phase motor currents and voltages.
- Motor shaft RPM.
- Load torque, current, and voltage.
- Motor flux.
- About 12 thermocouples at different locations in the motor, including the bearings.

4. Tabletop AC and DC Motor Experiments

The objective of the tabletop AC motor experiment is to understand how the motor current is affected due to variations in the load, and misalignment between the motor and the driven machinery (such as a fractional horsepower DC generator as the load). The effect on the current RMS value and the frequency characteristics of the motor current can be tracked by remote measurements.

In another experiment, a fractional horsepower DC motor is coupled to a shaft with varying flywheel mass attached to the shaft. The objective here is to monitor the rotating machinery during variable speed operation. Transient data may be acquired from the system either during speed-up or coast-down experiments. The *nonstationary* data are processed using time-frequency analysis so that changes in frequency characteristics may be monitored as a function of time.

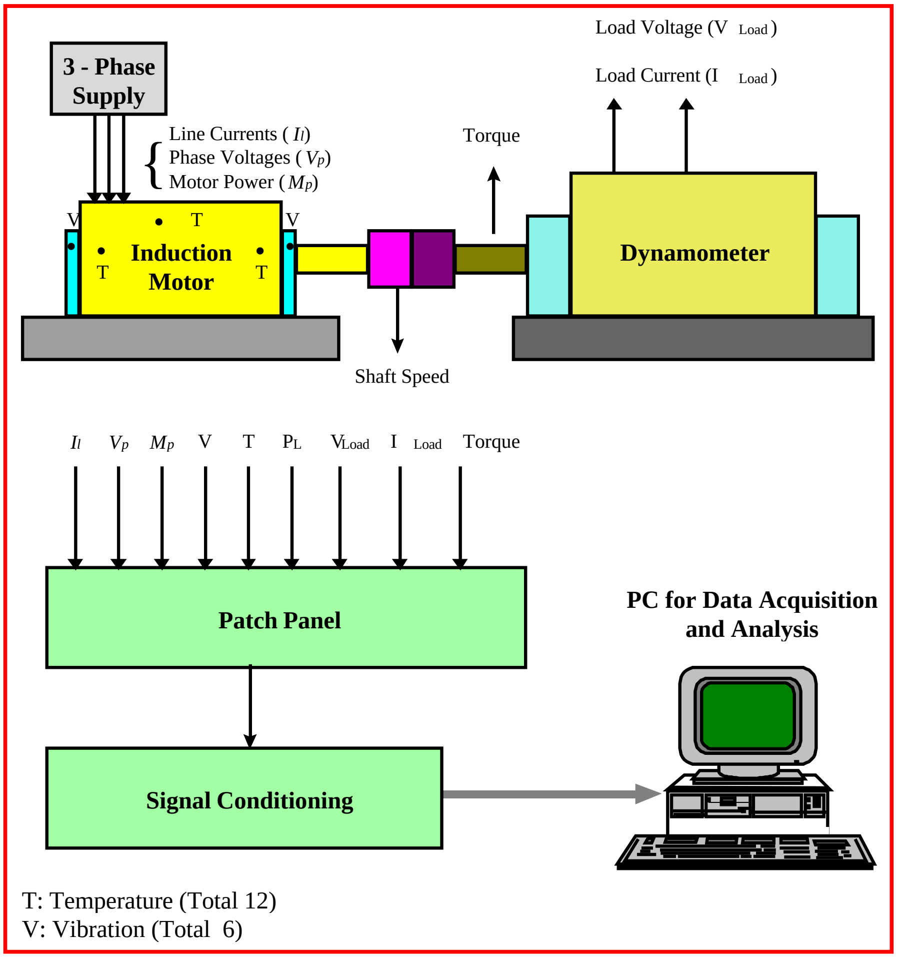

Figure 2. Schematic of the motor test laboratory, showing the interface between the sensors and the data acquisition computer.

5. Oil Analysis Module

A complete analysis of lubrication oil includes a *TriVector* approach developed by Emerson Process Management – CSI. This includes the analysis of oil samples for contaminants, wear particles, and chemical composition. The science of oil analysis is also referred to as *tribology*. The objective of the oil analysis module includes (1) the detection of ferrous particles, (2) measurement of water content, and (3) measurement of oil viscosity. In many machinery monitoring programs, the results of vibration analysis and oil analysis are combined to perform a highly reliable diagnostics of impending problems in rotating equipment.

6. Eddy Current Test Module

The objective of the eddy current test (ECT) module is to demonstrate the technique for detecting and isolating surface or near surface flaws in electrically conductive materials. One of the important applications of ECT is the detection and sizing of flaws in steam generator, heat exchanger, and boiler tubing used in power generating plants and chemical process plants. The defects in tubing are caused by stress corrosion cracking, pitting, mechanical wear, sludge deposits, and others.

ECT measurement is based on inducing small, circular currents in a test specimen. ECT uses high frequency AC current in a primary coil to generate a magnetic field, which in turn induces circular eddy currents in the material of interest. The ECT device obtains a signal by disruption of the eddy current due to a flaw in the test equipment, causing a change in the opposing magnetic field, and thus changing the coil impedance. ECT data consist of impedance plane signatures -- inductive reactance and resistance. Applications of ECT include detection and quantification of grain size, surface treatment, coating thickness, hardness, composition, cracks, inclusions, dents, holes, corrosion, etc.

The ECT module consists of the Zetec MIZ-22 Eddy Current Tester, a differential bobbin coil probe, a surface or spot probe, copper tubular specimen with notches and a circumferential groove, a steel pipe with a weld joint, variable thickness metal strip, and a plate with flaws. The Zetec system is interfaced with the PC for data acquisition and data processing.

7. Ultrasonic Test Module

Ultrasonic examination is a volumetric technique that uses sound waves (mechanical vibrations) with frequencies greater than the human hearing limit of approximately 20 kHz. The ultrasonic test frequency spans 0.5 – 10 MHz. Piezoelectric transducers are used to convert an electrical signal to sound waves in the specimen. The typical power and process industry applications use the *pulse-echo* ultrasonic technique. In this approach a transducer receives a high-frequency pulse that causes it to vibrate, generating ultrasonic waves in the piezoelectric material. The acoustic pulse travels through the specimen until it is reflected from either the back surface or some other discontinuity. The reflected waves are detected by the same transducer and the information is processed to determine the location of flaws. Applications of ultrasonic testing include thickness measurement, flaw detection and sizing, erosion-corrosion damage assessment, examination of piping, welding, bolting, turbine rotors, and plant structural components. Passive ultrasonic testing is used for leak detection.

The ultrasonic test module consists of an ultrasonic pulser/receiver board, A/D converter for PC data acquisition, a 5-MHz pulse-echo probe, and Plexiglas test samples. Both the location and the size of the defect may be measured with this approach.

8. Concluding Remarks

The development of a teaching laboratory facility, with emphasis on maintenance engineering, is presented and some of the highlights are described. The scope of the experimental modules ranges from rotating machinery monitoring, nondestructive examination, to lubrication oil analysis. The laboratory has been designed to compliment the classroom activities of courses on maintenance engineering and machinery monitoring and diagnosis.

A complete manual, that describes the principle, equipment, procedure, and laboratory exercises for each experiment, is available[4]. The teaching laboratory compliments the classroom discussion of the various topics. This is especially important in light of the topical content of the course and the varied background of students who are enrolled. The laboratory provides an opportunity for students to understand and appreciate the role played by condition-based maintenance technologies in increasing manufacturing productivity and quality. Plans are underway to enhance the scope of the laboratory by incorporating additional Internet access to machinery data acquisition and control.

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