Machine Diagnostics Revisited

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Abstract

For more than a decade, the Mechanical Engineering Technology (MET) Department at Purdue University has taught an elective course in machinery diagnostics. The course is designed to provide the knowledge and expertise needed in the field of condition monitoring, also known as reliability centered or predictive maintenance. Condition monitoring is increasingly widespread in industry, but is rarely incorporated into undergraduate curricula. This machine diagnostics course was developed to prepare engineering technology students for the sophisticated testing and analysis technology of the maintenance field. The conceptual content of the course has been relatively constant; however, the laboratory activities have evolved significantly to adopt additional technologies and software. This paper will review the original course design and compare it to recent course offerings, with emphasis on the ongoing effort to incorporate monitoring of a variety of operating parameters and to engage with industry.

Background

Through advances in solid-state electronics, instrumentation, and computing capabilities in the 1970s and 1980s, the field of machinery condition monitoring obtained the technology needed to make predictive maintenance a practical approach to maintaining rotating equipment. Previously the responsibility of consultants who analyzed the condition of a handful of critical machines, monitoring programs were expanded to include necessary supporting equipment (pumps, motors, compressors) and duties were shifted to a combination of skilled trades personnel, maintenance engineers, and technicians in-house[1]. This shift from consultants to maintenance professionals created an educational void, where graduate engineers and engineering technologists lacked the knowledge needed to successfully manage predictive maintenance programs[2].

An initial pilot version of MET 317 Machine Diagnostics was offered in the fall of 1990 to six senior Purdue University MET students to begin to address this missing educational component for maintenance professionals. A team approach was adopted to facilitate acquisition of equipment and development of laboratory activities[3]. The course was established on a permanent basis in 1992[4]. Table 1 lists the original course topic outline and laboratory activities. Minor changes to the lecture topics and ongoing significant laboratory evolution have occurred in the years since its inception. For more than five years now, the course has been offered at least twice a year for up to thirty students per session.

Several mechanical engineering and mechanical engineering technology programs have developed machinery vibrations courses[5]. In an approach that appears to still be unique to the Purdue University diagnostics course, multiple operating parameters are studied. Students learn which operating parameters are the best indicators of specific machine problems. Vibration allows the detection of more problems than other parameters, and receives the most extensive coverage in the course. Temperature, lubricant contamination, and noise are also introduced.

Table 1: Original MET 317 Topic Outline

Week(s)	Topic	Laboratory Activity(ies)
1,2	Vibration Fundamentals (SDOF)	Natural frequencies, damping in cantilever beams Forced vibration and isolation
3,4	Vibration Instrumentation – Sensors, Meters, and Analyzers	Transducer mounting effects
5	Data Acquisition and Interpretation	Introduction to semester project
6,7	Unbalance and Dynamic Balancing	Visit to precision balancing facility for balancing demo Single and two-plane balancing
8	Vibration in Bearings	Bearing vibration measurement
9,10	Vibration due to Misalignment, Looseness, Bad Belts, and Gears	Laser alignment demo at extrusion plant Misaligned motor detection and correction
11	Predictive Maintenance	Visit to power plant including monitoring of power plant fan system vibration
12,13	Noise Fundamentals and Measurements	Noise measurement from multiple sources
14	Applied Thermal Measurements	Infrared temperature measurement on an assembly line
15	Lubrication	Patch-test lubrication analysis
16	Final Exam	Project presentations

Ongoing challenges for the Machine Diagnostics course

Offering a multidisciplinary laboratory-based course has been a challenge from its inception. The challenges include:

- High startup cost for each parameter that is incorporated into the laboratory
- Keeping three groups of four to five students occupied in meaningful learning experiences when instrumentation, software, and test stands are only available as one or two units each
- Dependence upon ongoing industry participation to broaden opportunities for equipment exposure and projects
- Finding the optimum mix of course topics
- Finding a textbook that addresses most course topics
- Integrating new technology and equipment into the course
- Incorporating new lab activities as industry practices evolve

Nearly all of the above challenges are common to engineering technology courses, where the goal of providing students learning experiences that will result in readiness for industry is tempered by financial and time costs. Obtaining sufficient equipment to provide state of the practice experiences, when typical items of software and hardware each cost well beyond the $10,000 mark, has been a struggle. The generosity of a number of companies in donations of time, equipment use, and equipment has made the course feasible and has greatly impacted the mix of topics in the course. Current course equipment is listed in Table 2.

Table 2: Abbreviated Course Equipment Listing

Test Equipment (Quantity)	Test Stands
dataPAC 1500 data collector (2)	Single-plane balance stand
IRD 890 data collector (2)	Dual-plane balance stand
Accelerometers, industrial grade (8)	Alignment stand
Infrared temperature sensors (3)	Transmissibility stand
Laser alignment kit (1)	Belt-drive stand
Stroboscope (2)	Resonance-mode stand
Tachometer (3)	
Patch test kit (1)	
Ultrasonic detectors (3)	
Sound level meter with filtering (1)	
Oscilloscope (1)	
Function generator (1)	
Miscellaneous mechanics test equipment	

Evolution of course topics

It was immediately clear that the first offering of Machine Diagnostics did not provide sufficient exposure to condition monitoring software to give students confidence in setting up a monitoring route and trending. By the third course offering, this area regularly received multiple hits. First, students learn to access, test, and upload route data collected in the laboratory. Next, they follow power plant personnel through a short section of a regular vibration monitoring route and make a cursory attempt to analyze the resulting frequency spectra. Figures 1 and 2 show one version of the power plant monitoring route and a representative frequency spectrum, respectively.

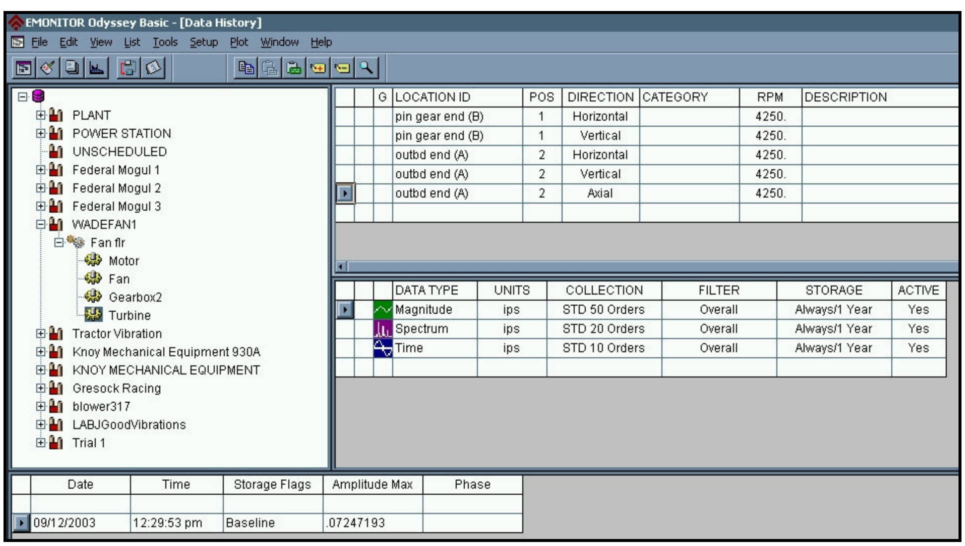

Figure 1: Example of Vibration Monitoring Route

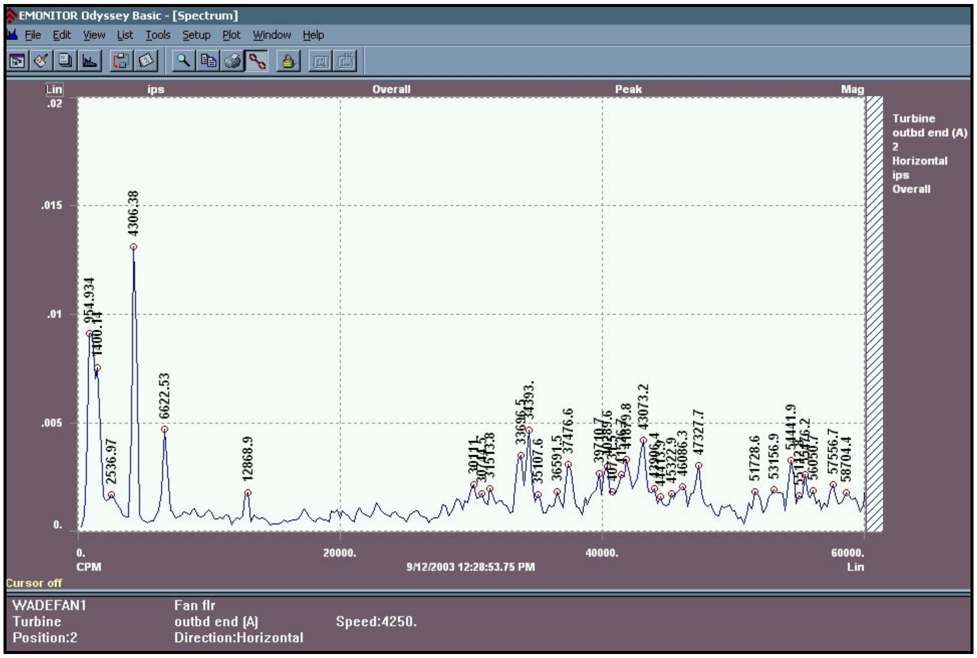

Figure 2: Sample Frequency Spectrum

Once students have learned the basics of the monitoring software, they subsequently design and generate their own route for monitoring mechanical equipment in the laboratory building, collecting, trending, and analyzing the data they obtain. Ultimately, most students incorporate monitoring software into their semester project. All students become reasonably familiar with the monitoring software to set up a route and produce plots and reports.

The three most common equipment operating parameters to monitor are vibration, lubrication contamination/condition, and temperature[1]. Temperature monitoring at course startup included infrared temperature readings at a point, rather than a thermogram showing surface temperature over an area. Temperature changes at a single location can be useful for trending, but temperatures tracked over a larger area are more likely to permit detection of developing heat problems. Heat transfer concepts are presented elsewhere in the MET curriculum, so discussion of temperature monitoring focuses on the instrumentation and thermal monitoring analysis. Guest speakers who demonstrate their equipment have been the solution to this problem. At each course offering, one class session is devoted to a presentation of typical monitoring situations where thermography quickly shows the surface heat generated by a system problem. Students gain an understanding of the context in which non-contact thermal data can be used as an appropriate diagnostic tool. For laboratory and project work, students are presently limited to point temperature readings.

Leaks and vibration from minor bearing defects can be detected using ultrasonic inspection. Through the generosity of the thermography guests, demonstrations of ultrasonic testing were brought into the course in 1995. They subsequently donated an ultrasonic detector that students use in two laboratory modules and may use in their semester projects.

Audible noise has gradually become a less significant course topic. It has not developed into a practical monitoring parameter for most machine installations. Noise remains, however, a safety concern for maintenance personnel and a good venue for including continuous wave motion considerations in the course. Noise testing is introduced through measurements of sound pressure level using a standard sound level meter in one laboratory session.

Laser alignment was demonstrated at a plant visit for the first course offering, with dial indicator-based methods used in the course laboratory. Time and personnel constraints made this approach difficult to sustain. The company instead opted to provide funds to purchase a laser alignment kit. For a couple of years, the students only received exposure to laser alignment through course resources. When the local distributor changed in 1999, the new representative offered to demonstrate their latest model to the class. The demonstrations have continued, and in addition, the company has donated training CDs to the class to allow more thorough preparation before students tackle their motor alignment.

The current course outline provided in Table 3 shows the incorporation of each of the items discussed in detail above. It also shows various minor changes that have occurred in the course content. Some examples include a greater amount of time spent on vibration fundamentals, a signal processing simulation in the laboratory, and an introduction to flow-induced vibration. In general, this evolved course outline, with major modifications shown in italics, provides a more organized and integrated approach to machine diagnostics concepts and applications.

Table 3: Current MET 317 Topic Outline

Week(s)	Topic	Laboratory Activity(ies)
1,2	Vibration Fundamentals, SDOF Free Vibration	*Introduction to monitoring measurements, equipment, and software* Natural frequencies, damping in cantilever beams
3,4	SDOF Forced Vibration, Transmissibility/Isolation	Forced vibration and isolation Visit to power plant including monitoring of power plant fan system vibration Introduction to semester project
5,6	Vibration Spectral Analysis, Maintenance Practices, Vibration Standards, Sensors	*Setup of monitoring route and initial data collection* Transducer mounting and additional monitoring measurements (temperature, ultrasonics)
7	Data Acquisition, Signal Processing	*Signal processing simulation*[6] *Beam modes and mode shapes*
8,9	Unbalance and Dynamic Balancing	Visit to precision balancing facility for balancing demo Single- and two-plane balancing
10,11	Misalignment and Alignment, Temperature and Infrared Thermography	Laser alignment demo Misaligned motor detection and correction *Thermography and ultrasonics demo*
12,13	Vibration Due to Bearings, Belts, Gears, Looseness, and Flow Concerns	*Second run of data collection on monitoring route and trend analysis* *Vibration due to bearings, belts, and looseness*
14,15	Lubrication, Noise Fundamentals	Noise measurement from multiple sources Patch-test lubrication analysis *Flow-induced vibration case studies*
16	Final Exam	Project presentations

Course projects

As the course has evolved, the semester projects have changed in scope so that they continue to "expand student knowledge of course topics beyond what is covered in the classroom". Typically, the projects fall into three categories: (1) analysis, diagnosis, and possibly solution of a specific machinery vibration problem; (2) development and implementation of a monitoring route, including trending analysis; and (3) investigation of a monitoring parameter other than vibration, to develop criteria for and limitations of its use. All projects require detailed measurement and analysis, a written report, and an oral presentation.

The instructors have emphasized the opportunity to serve local and Indiana companies through the application of course knowledge to their unresolved problems. Since this course is one of a very few within the MET Department elective courses that allow students to define their own semester project, this service learning opportunity is frequently ignored. In practice, the service component may be more from the company to the student team. Despite the instructors' lack of success in ensuring the students have a service learning experience, the projects have been sufficiently open-ended and have had good enough results to be a regular positive factor in employment decisions, according to the students. A listing of representative project titles is shown in Table 4, and one of the more practical projects can be reviewed[7].

Table 4: Sampling of Semester Projects

Year	Title	Description
1990	Electric Motor Analysis	A two-motor system with flywheel attached was thoroughly measured to diagnose the sources of its elevated vibration.
1993	Knoy Hall Air Handling Systems Monitoring	A predictive maintenance route was established for the air handling equipment in the Knoy Hall mechanical equipment room. Vibration data was collected, trended, and analyzed to diagnose existing problems.
1995	Surface Grinder Analysis	A vibration analysis of a surface grinder was conducted to determine its condition and recommend corrective actions.
1997	Parking Garage Analysis	Students conducted the second phase of a study of why premature failure of overhead parking garage lights regularly occurred. Project verified that the natural frequency of the ballast coincided with structural vibration in the garage.
1999	New Fan Hub Assembly Balancing	Students investigated the sources of imbalance in a new fan hub assembly. Testing of the new hub components was completed on an industrial balancer, then checked for resonances (for two hub sizes).
2000	Truck Vibration at Peak Torque	Students tested the vibration levels of a diesel truck, with and without a TST, Incorporated Power Kit, to relate vibration level and torque at a range of operating speeds.
2001	Ultrasonic Testing	An ultrasonic survey of the air lines in an industrial facility was conducted to locate all leaks. Noise testing was also performed to verify compliance with regulatory requirements.
2003	Tractor Noise and Vibrations	Students measured the noise and vibration of a Deere 8420 tractor and analyzed the resulting data.

Course impact

One indication of the impact of the MET 317 course is simply the popularity of the course. The course has been offered every semester (excluding summers) for over five years, with up to 30 students enrolled each semester. There has been a significant waiting list for the course each semester. Over the past three semesters, student ratings of the overall course have averaged a 4 on a scale of 5 (with 5 being excellent and 1 being very poor).

As an additional assessment of the benefits of the Machine Diagnostics course, informal feedback from MET graduates who completed the course has been collected. Recent graduates have taken their MET 317 experiences into fields such as plastics manufacturing and vibration isolation product engineering. In industry, former MET 317 students have regularly been called to use vibration fundamentals to calculate natural frequencies and displacements for simple spring-mass-damper systems. Graduates also testify that they have supplied information from the MET 317 course to colleagues at work, as their employers look to implement additional predictive maintenance capabilities. The industry guest speakers are frequently contacted for additional information relating to their class demonstrations and the associated products.

Future course direction

The current version of the Machine Diagnostics course provides a broad overview of machinery analysis and maintenance practices, with good opportunities for student engagement with industry. In an ongoing effort to strengthen the course, the following improvements are under consideration for future course offerings:

- Increased coverage of Total Productive Maintenance (TPM) to link to lean manufacturing
- Exposure to Computerized Maintenance Management System (CMMS) software
- Ability to include additional monitoring parameters in current software database
- Improved interaction with industry through greater number of service learning projects with local industry

As additional companies recognize the positive economic impact to be realized through extended equipment life and reduced unplanned downtime, the demand for condition monitoring professionals can be expected to continue to grow. The Purdue University MET Department plans to keep addressing a portion of this demand through the MET 317 Machine Diagnostics course.

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Biography

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