ME 7690: Vibration Testing

Description

This course covers advanced theoretical and practical aspects of vibration testing including: signal analysis, windowing, transducers, exciters, modal identification techniques, rotor dynamics, and health monitoring.

Instructors

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Helpful materials are available through the course page

Prerequisites

ME 4210/6210: Engineering Vibration or equivalent

Time and Location

Tuesday/Thursday 11:00-12:20, 141 Russ Engineering Center

Lecture:

The course is Lecture/Lab. Lab is at your own pace, but some lectures will actually be introductions to the Vibration Lab (010 Russ). Lecture time will be shortened accordingly to accommodate the extra time spent in the lab.

It will be relatively fast-paced (I hear). You are expected to meet one-on-one with the instructor throughout the semester as much of the class is run as an individually scheduled lab.

Lab:

139 Russ. Open hours (unless scheduled for other use). One lecture early in the semester will be in the lab. After that, you will use the lab equipment at times of your convenience in order to complete assignments but their due dates. You are expected to be proactive in asking for equipment, as well as read manuals as necessary to enhance your skills.

141. Russ Open hours (unless scheduled for other use). This is the same room that class will be held in.

Texts

Required

Vibration Testing, with Modal Analysis and Health Monitoring, J. C. Slater.

Will be provided as a PDF during class.

Supplementary

Engineering Vibration, D. J. Inman.

Theoretical and Experimental Modal Analysis, N. M. M. Maia and J. M. M. e Silva, 1998.

Turbomachinery Rotordynamics: phenomena, modeling, and analysis, D. Childs, 1993.

Mechanical Vibrations, J. P. Den Hartog

Modal Testing: Theory and Practice, D. J. Ewins.

Vibration for Engineers, A. Dimarogonas.

Vibration Testing, K. G. McConnell.

Random Data Analysis and Measurement Procedures, 3rd edition, J. S. Bendat and A. G. Piersol, 2000.

Random Vibrations: Theory and Practice, P. H. Wirsching, T. L. Paez, and K. Ortiz, 1995.

An Introduction to Random Vibrations, Spectral & Wavelet Analysis, 3rd edition, D. E. Newland, 1993.

Software

A wide variety of scripts in Matlab and Python will be used in this course. It is necessary that you at least have Matlab installed, and highly recommended that you install Python. You will also learn how to use GitHub (why to use git) to do collaborative software development. Get and account as early as possible and learn how to fork

1. Get an account on GitHub. Think of this as a Facebook for professional coding. This may become valuable for you as a resume to future employers.
2. Install GitHub Desktop
3. Read through all of the Guides. You will not remember everything. That is OK. You will learn some of it and it will help you later.
4. Work with the Spoon-Knife example.

Please see a Glossary of some of these terms.

I think you should (but it's not necessary for the course):

1. Get the free Student Developer Pack
2. For command line knowledge (once you understand the GUI) Introduction to command line git. I plan on watching this carefully. It's full of good knowledge.

Matlab

Matlab is available at no direct charge to students. It is already installed on the lab computers. Please also install the following on both your lab accounts and on your personal computers.

Matlab packages that will be used are:

1. The Engineering Vibration Toolbox: Install the Matlab version.
2. The Vibration Testing Toolbox for Matlab. This version is working, but is not being developed with advanced capabilities. So, codes in this package work well, but are limited.

Python

Python is an open-source and free language that is currently ranked the second most sought after language by companies (Matlab is barely in any rankings). It is faster than Matlab, much more widely developed (because everyone can contribute to it, and more broadly applicable (Youtube and Dropbox are in large parts Python code). You need to install it via the link and instructions.

Two Python packages will be used. They include more advanced features and are being actively developed. It is recommended that you install them via the developer method. This will allow you to:

1. Contribute fixes and code (for credit)
2. Easily receive updates during the term.

To do this, create an account on GitHub. Install the GitHub Desktop Application, then follow the instructions for installing as a developer:

1. Installing the Engineering Vibration Toolbox for Python (See *contributing code*)
2. Installing the Vibration Testing Toolbox for Python (See *contributing code*)

For a tutorial on how to work with forks, please see the Spoon-Knife tutorial repository. It is well worth your time.

Topics

1. Review of introductory vibration theory.
2. State-space analysis.
3. Introduction to probability theory.
4. Signal processing: Correlation, Fourier Analysis, Spectral Density, Cross Spectral Density, Frequency Response Functions (H_1, H_2, and H_v, MIMO).
5. Digital signal processing: discrete Fourier Transforms.
6. Data windowing and the effects on identified parameters.
7. Transducers: characteristics, calibration and selection.
8. Exciters: Hydraulic, electric, reaction-mass, rotating unbalance, hammers.
9. Basic identification techniques - errors induced.
10. Modal Identification: Polyreference and Eigensystem Realization Algorithm Techniques.
11. Model correction techniques.
12. Rotor Dynamics: De Laval rotor, whirl, precession, damping (hysteretic and viscous), gyroscopic effects, bearing instabilities.
13. Health monitoring: Signal processing techniques, Campbell Diagram, Cepstrum Analysis, Gating, Fault Diagnosis.

Homework (10%)

Homework problems will be assigned at the end of lectures. *Any statement in the book such as "it can be shown", "left as a homework problem"... is to be treated as a homework assignment when the material is covered in class. All problems at the end of the chapter should be done as well.* Homework problem solutions are collected every Thursday. You will be given no less than one week to do them. If there is a test scheduled on a day homework is due, the homework will be collected the following Wednesday. Each homework problem's worth will be scaled by difficulty, based on the number of students who complete the problem. Standard scale is 1 point. If only one person solves the problem, the problem will be scaled to 5 points.

Students are encouraged to generate their own homework problems, turning the problem in to the instructor, along with the solution.[#foot]_ These will also be assigned to the class. One additional bonus point will be assigned provided the solution is also provided. Students may submit up to five problems per week, provided that they are unique from others submitted (just changing the numbers does not make the problem unique). *Students may not copy problems out of another text* for the bonus points, but may propose them as a challenge to the class provided that they announce the source of the problem. *The instructor reserves the right to assign or not assign any particular problem based on its merits relative to the course material.*

Your final homework score is your average total score divided by the total number of possible points. You are encouraged to work together in small groups, but keep in mind that homework is assigned in order to help you learn and keep up with the course material. Also note that you are strongly rewarded for distinguishing yourself. Please see me if you need help with the homework. This class is a cooperative effort between you and me. Homework scores will be curved to a nominal 3.5 average or better.

Exams (50%)

There will be one midterm and a final exam graded on a curve, with the average nominally being 3.5 on a 4 point scale. Minimum scale is $\geq 90 = A, \geq 80 = B, \geq 70 = C, \geq 60 = D, < 59 = F$. The final exam will count for two test grades. The lowest exam grade of the three will be dropped. An 8.5 in. by 11 in. formula sheet may be used provided there are no derivations, definitions or solved problems on the sheet. Tests will be graded and returned as soon as possible. Solutions will be discussed during the lecture following the exam if time permits. All grading discrepancies must be brought up in writing no later than one week after the exam is returned. A simple note describing your contentions will do.

Labs (40%)

Labs involve additional research outside of the classroom, as well as some programming for data analysis. Students should consult the books on reserve at the library in addition to their own texts. In addition, it is expected that students will need to consult me before, during, and after performance of the labs.

Students will work in pairs on the standard labs.

Alternate labs may be proposed by students. Students who have specific research needs should take advantage of this opportunity to tune their learning to their specific needs. Examples are identification of noise floor, PDFs, and sources in lab experiments, identification of sensor capabilities, etc. Depending on the depth of the proposed experiment, it may be substituted for more than one below.

At least five of the following labs must be performed and documented to an adequate level to receive a B grade. Students must perform *Lab 1*, at least one of *Lab 2*, *Lab 3* or *Lab 4*, plus two rotor-dynamics labs. Labs are open-ended learning experiences. Grading will reflect documented understanding gained in the lab. All data generated in the labs must be a) plotted and described in the report, b) turned in to me in `.mat` or ASCII format (preferred) format. Report must be hard-copy. The report with the raw data must be zipped, tar-zipped, stuffed, or what ever compression format you choose, into a single archive and emailed to me. Lab grades will be curved to an nominal average of 90% or better.

1. Lab 1: Introduction to lab equipment, hammers, load cells… Use of hammer to obtain time and frequency data. Experimentation with windowing. Identification using ERA (EzERA on the MathWorks web site, by Dr. Richard Cobb) and FRF (`mdofcf.m` or similar from instructor) curve fit, half-power peak picking, and Nyquist circle fit to identify natural frequencies and damping ratios for the first 5 modes.
2. Lab 2: Sine sweep experiment and random excitation experiment, repeat identification methods of Lab 1. Comparison of results to those of Lab 1.

3. Lab 3: Repeat first two labs. Use different FRF techniques (see text) in order to estimate noise levels in each test.
4. Lab 4: Modal analysis using ERA and Polyreference.
5. Lab 5: Modal analysis of an object, correcting for mass loading of cables/accelerometers using perturbation methods.
6. Lab 6: Estimation of rotating unbalance. One plane balancing.
7. Lab 7: Estimation of sensitivity to misalignment.
8. Lab 8: Identification of bad bearings (choose your bad type based on available cases).
9. Lab 9: Identification of number of bad teeth in gear.

Important Dates

September 28:	Exam I
November 6:	Exam II
December 14:	Final Exam, 10:15-12:15

HW and Other Assignments

- Homework (assigned in class until otherwise notified)__
- Data for homework problems