MECH 463 -- Mechanical Vibrations

Dr. G. S. Schajer. Term 1. 2019/20. 4 credits.

This course is designed to develop knowledge and understanding of the vibration of mechanical systems, and to give some experience in making practical vibration measurements. The basic principles learned in previous courses are applied and extended to describe the vibration of multiple degree-of-freedom and continuous systems. This course emphasizes understanding and application of fundamental concepts.

Suggested text: "Mechanical Vibrations: Modeling and Measurement", T.L. Schmitz and K.S. Smith, Springer, 2012.

You can freely download an electronic copy of this textbook from the UBC library. Connect to Springerlink https://link-springer-com.ezproxy.library.ubc.ca/ when using a campus IP address, search for "Mechanical Vibrations" and download.

Strong recommendation: For US$24.99, go ahead and buy a printed softcover book using the "MyCopy" button on the right side of the Spingerlink page. A printed book is much easier to read and study from than an electronic file, leading to better understanding and enhanced grades.

The class discussion loosely follows the presentations in the textbook. There is no monopoly of wisdom and many other books can give useful additional insights and alternative points of view. Springerlink contains many materials about vibrations, also numerous other subjects. The UBC library catalogue lists 100+ titles under the keyword "Vibrations."

The coursework includes the following components:

1. Lectures: Tu-Th, 8:00-9:20 am, Swing 222.
2. Tutorials: A = Mondays ESB 2012 4-5pm, B = Wednesdays CEME 1204 noon-1pm, C = Tuesdays FSC 1003 5-6pm.
3. Two lab experiments done in groups of three students. Lab schedule TBA in class.
4. Twelve homework assignments. Solutions will be distributed after one week. Although not formally marked, these assignments are an essential part of the course. Practice gives understanding – best to discover conceptual gaps at home, not in the exam room.
5. Two mid-term exams and a final exam. You may bring one 8x11" sheet (one side only) of your personal handwritten notes to each exam.

Grading Scheme:

20%	Lab experiments
20%	Mid-term 1
20%	Mid-term 2
40%	Final Exam

TAs

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COURSE OUTLINE

The course materials will be chosen from among the following topics :

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1.	**1-DOF Review:** Review of the vibration of 1 degree-of-freedom systems. Free body diagrams. Trigonometric and complex solutions. Damping. Forced response. Magnification factor.	2.1 2.3, 2.4 3.1-3.3
2.	**Vibration Testing:** Displacement and acceleration measurements. Spectrum analyzers. Machinery condition monitoring.	2.6, 7.3 1.4, 1.5
3.	**2-DOF Systems:** Characteristic equation. Mode shapes. Matrix formulations and solutions. Eigenvalue formulations.	4.1,4.2
4.	**Mathematical Properties:** Semi-definite and unstable systems. Coordinate coupling. Principal coordinates. Proportional damping. Lagrange equations. Orthogonality of mode shapes. Rayleigh Quotient.	4.3,4.4
5.	**Forced Vibration:** Forced response. Undamped and damped vibration absorbers.	5.1, 5.2 5.3, 5.4
6.	**Continuous Systems:** Wave equation. Separable solutions. String, rod and beam examples. Approximate solution methods.	8.1, 8.2 8.3

EXPERIMENTS:

1. 1-DOF Vibration Measurement of a Damped Engine Mounting. Illustrates use of accelerometers and associated instrumentation to make typical vibration measurements.
2. Multi-DOF Vibration Measurement of a Damped Engine Mounting. Illustrates use of an spectrum analyzer to identify natural frequencies and mode shapes of a multi-DOF system.

Free Vibration of a 1-DOF System

The equation of motion for free vibration of a 1-DOF system is :

$$m\ddot{x} + kx = 0$$

where m is the mass, k the spring stiffness, and x the vibrational displacement measured from the equilibrium position. The undamped natural frequency $\omega = \sqrt{(k/m)}$. The solution to this equation can be written in several different forms. These different solution forms are all mathematically equivalent, even though they have different appearances. In theory, any one of them can be used for any calculation. However, each solution form has different advantages and disadvantages, and a judicious choice of a particular one can make certain calculations much simpler. Conversely, a non-optimal choice can lead to much tedious algebra.

The following are four different solution forms, each with particular advantages and disadvantages.

$$x = A\cos\omega t - B\sin\omega t \tag{1}$$

Advantages: Linear trigonometric form.

Disadvantages: A and B do not have obvious physical meanings.

$$x = C\cos(\omega t + \phi) \tag{2}$$

Advantages: Trigonometric form. C is amplitude, ϕ is phase lead.

Disadvantages: Non-linear combination of constants.

$$x = G e^{i\omega t} + H e^{-i\omega t} \tag{3}$$

Advantages: Can easily be generalized to apply to damped systems.

Disadvantages: Uses complex numbers. G and H have no physical meanings.

$$x = \mathrm{Re}[\,D e^{i\omega t}\,] \tag{4}$$

Advantages: D contains both amplitude and phase. Useful for damped systems.

Disadvantages: Uses complex numbers. Non-intuitive.

Relationships among the equations:

$A = C\cos\phi \qquad B = C\sin\phi \qquad C = \sqrt{(A^2 + B^2)} \qquad \tan\phi = B/A$

$G = \tfrac{1}{2}(A + iB) \qquad H = \tfrac{1}{2}(A - iB) \qquad A = (H + G) \qquad B = i(H - G)$

$D = A + iB = Ce^{i\Phi} \qquad |D| = C \qquad \angle(D) = \phi$

Lecture 1

Proposed Lab times (flexible):

Monday: 1-3
Tuesday: 10-12
Wednesday: 3-5
Thursday: 12-2
Friday: 9-11

Lab Location: ICICS X050 (near PACE)

First lab next Friday (13th)

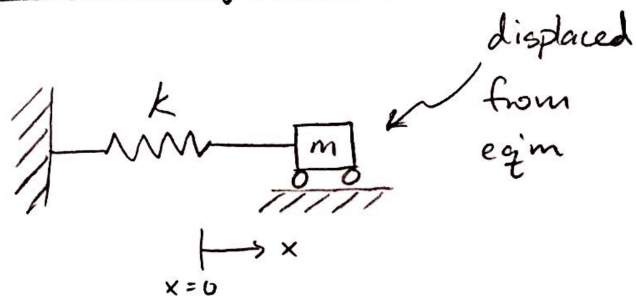
Sign-up for teams on page outside Schajer's office,
opens tomorrow (6th)

Office hours: catch Schajer after class or
go to office, or send email.

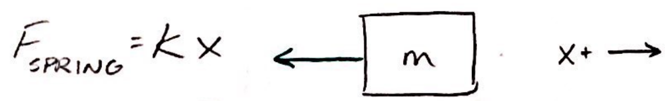
For TA: Tuesdays 11-12, 1-2
Office TBA

One degree-of-freedom (DOF) system

Mass-spring system:



FBD of mass:



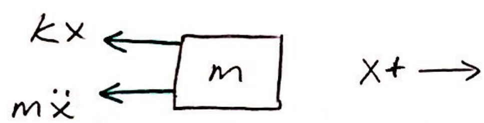
Newton: $-kx = m\ddot{x}$ ($\ddot{x}$ is acceleration)

$\Rightarrow m\ddot{x} + kx = 0$

D'Alembert's method: "Inertial force"

$F - m\ddot{x} = 0$ $\Rightarrow$ Pseudo-equilibrium

The D.A. FBD:



↳ Draw $m\ddot{x}$ opposite of x+ direction. because of $-m\ddot{x}$

↳ "Pretend" $\Sigma F = 0$

↳ $-kx - m\ddot{x} = 0$

$m\ddot{x} + kx = 0$ (as expected)