Systems Design 652

Dynamics of Multibody Systems

Instructor:
Prof. John McPhee
E3-4114, ext.35341
mcphee@real.uwaterloo.ca

Lectures:
Tuesdays@2:00-3:30 p.m.
Thursdays@2:00-3:30 p.m.
(E5-6002)

Web Page:
http://real.uwaterloo.ca/˜mcphee/sd652/sd652.html

Evaluation:
Assignments = 60 %
Project = 40 %

Course Description:

Essentially, this course shows how an engineer can efficiently model and simulate the motion of complex mechanical systems such as robots, vehicles, and mechanisms. Systematic methods, including conventional approaches and linear graph theory, are used to generate kinematic and dynamic models for 2-d and 3-d systems of rigid bodies connected by mechanical joints, springs, dampers, and actuators. The extension of these methods to vehicles, mechatronic systems and flexible robot manipulators is also presented. Numerical solutions for the dynamic equations provide a simulation of the system response, which will be obtained using commercial software packages (ADAMS and MapleSim). The course concepts are demonstrated through applications to the kinematic and dynamic analysis of mechanisms, serial and parallel robot manipulators, road and rail vehicles, and other industrial multibody systems. Whenever possible, mechanical prototypes are brought to the lectures.

Course Contents:

I. Review of Kinematics and Dynamics: A quick review of the material in SD 182/ME 212 and SD 553/ME 524, including degrees of freedom, particle and rigid body kinematics, moving reference frames, Newton-Euler equations, principle of virtual work, and Lagrange's equations.

II. Conventional Multibody Dynamics: The student is shown how commercial packages like ADAMS and Working Model can automatically generate and solve for the response of complex multibody systems. Shortcomings of these methods are discussed, as well as issues related to kinematics, forward and inverse dynamics, and singularities. We start with planar systems, to understand the basic theories, before moving on to three-dimensional multibody systems.

III. Advanced Modelling of Multibody Systems: Vectorial methods are used to create the constitutive equations for rigid bodies, revolute and prismatic joints, translational and rotational spring/damper/actuator components, applied forces and torques, and kinematic drivers. These component models are then combined to form multibody systems, the equations for which are automatically generated using linear graph theory and principles of mechanics. Numerical solution methods will be briefly reviewed, and Matlab routines will be used to solve the equations generated by the students for a variety of kinematic and dynamic applications. We will then use MapleSim, a commercial package that uses graph-theoretic algorithms, to generate symbolic equations and simulations for multibody applications.

IV. Advanced Applications: Finally, the student is introduced to some advanced topics in multibody dynamics, including:

- modelling of tires in vehicle dynamics
- modelling of contact dynamics
- modelling of flexible bodies (e.g. elastic beams)
- incorporation of elements from other physical domains (e.g. hydraulic, electronic, pneumatic) into the system model. Several robotic and mechatronic examples will be presented.

Reference Materials

There is no published monograph that could be used as a single course textbook. The initial part of the course is supported by the out-of-print text by Haug [1]; inexpensive copies of the first half of this book are available at the bookstore. The text by Nikravesh [2] has much of the same material. The material on advanced modelling is covered in the set of course notes [3], which are available from the course web page.

Many advanced topics in multibody dynamics can be found in the excellent book by Garcia de Jalón and Bayo [4], now available on the Web. In the UW library, one can find other books on multibody dynamics [5-6], mechanism and machine theory [7-8], and advanced dynamics [9]. The latter is particularly useful for the review of kinematics and dynamics in the first weeks of the course. Reference [10] is a good overview of the basics of systems modelling. Finally, there are several journals [11-13] that publish the latest research in multibody system dynamics.

1. *Computer-Aided Kinematics and Dynamics of Mechanical Systems*, Haug, Allyn and Bacon, 1989.
2. *Computer-Aided Analysis of Mechanical Systems*, Nikravesh, Prentice-Hall, 1988.
3. *Dynamics of Multibody Systems: Conventional and Graph-Theoretic Methods*, McPhee, SD 652 Course Notes, 2004.
4. *Kinematic and Dynamic Simulation of Multibody Systems*, Garcia de Jalón and Bayo, Springer-Verlag, 1994 (http://mec21.etsii.upm.es/mbs/bookPDFs/bookGjB.htm).
5. *Computational Methods in Multibody Dynamics*, Amirouche, Prentice-Hall, 1992.
6. *Dynamics of Multibody Systems*, 2nd ed., Shabana, Cambridge University Press, 1998.
7. *Mechanism Design: Analysis and Synthesis*, 4th ed., Erdman, Sandor, and Kota, Prentice-Hall, 2001.
8. *Design of Machinery*, 2nd ed., Norton, McGraw-Hill, 2001.
9. *Advanced Engineering Dynamics*, 2nd ed., Ginsberg, Cambridge University Press, 1995.
10. *Engineering Systems: Modelling, Analysis, and Design*, Chandrashekar and Savage, SD 351 Course Notes, 1997.
11. *Multibody System Dynamics*, Kluwer.
12. *Mechanics Based Design of Structures and Machines*, Marcel Dekker.
13. *Journal of Computational and Nonlinear Dynamics*, ASME.