wb1413-4
Multibody Dynamics B
A How-To Course

Spring Term 2013, Thu 15:45-17:30, room EWI-CZ C, 4 ECTS credits

Instructor:
Arend L. Schwab
a.l.schwab@tudelft.nl
Laboratory for Engineering Mechanics (PME), Mechanical Engineering (3mE), TUDelft
room 34-G-1-350, phone 015 278 2701, Office hours: Mon. 14-16 h.

Teaching Assistant:
Patricia Baines, Maryam Sharify & Ivana Nanut
p.m.baines@student.tudelft.nl, m.sharify@student.tudelft.nl & nanutivana@yahoo.it
room 34-G-1-365, phone 015 278 5376, Office hours: Mon 11-14 h. & Wed 14-17 h.

Introduction

In this course we will cover a systematic approach to the generation and solution of equations of motion for mechanical systems consisting of multiple interconnected rigid bodies, the so-called multibody systems. This course differs from "advanced dynamics", which mostly covers theoretical results about classes of idealized systems (e.g. Hamiltonian systems), in that the goal here is to find the motions of relatively realistic models of systems (including, for example, motors, dissipation and contact constraints).

By the end of the course you will be competent at finding the motions of linked rigid body systems in two and three dimensions including systems with various kinematic constraints (sliding, hinges and rolling, closed kinematic chains). Collisional interactions will be considered in a unified manner for all the different ways of formulating the equations of motion.

There will be weekly homework assignments and a final project. The homework is normally due a week after hand out and will be graded. The homework is strictly individual but in doing the homework I encourage you to work together and to use computer software like Matlab, Maple, Adams, Working Model etc.

Course topics

- Newton-Euler equations of motion for a simple planar system, free body diagrams, constraint equations and constraint forces, uniqueness of the solution.
- Systematic approach for a system of interconnected rigid bodies, virtual power method and Lagrangian multipliers.
- Transformation of the equations of motion in terms of generalized independent coordinates, and Lagrange equations.
- Non-holonomic constraints as in rolling without slipping, degrees of freedom and kinematic coordinates.
- Unilateral constraints as in contact problems.
- Numerical integration of the equations of motion, stability and accuracy of the applied methods.
- Numerical integration of a coupled differential and algebraic system of equations (DAE's), Baumgarte stabilisation, projection method and independent coordinates.
- Newton-Euler equations of motion for a rigid three-dimensional body, the need to describe orientation in space, Euler angles, Cardan angles, Euler parameters and Quaternions.
- Equations of motion for flexible multibody systems, introduction to Finite Element Method approach, Linearised equations of motion.

Upon request and if time and ability of the instructor allows, related topics are open for discussion.

Homework

There will be weekly homework assignments and a final project. The homework is due a week after hand out and will be graded. Hand in your homework at the start of class at the front. Graded homework can be picked up (next week) at the end of class or at the TA's office. In doing the homework I encourage you to work together within the rules and regulations.

Rules and Regulations:
To get credit, on every homework assignment please do the following things:

1. On the top right corner neatly print the following, making appropriate substitutions as appropriate:

   ```
   Sally Rogers, # 9123456
   HW set 1, Due Aug 31, 2004
   wb1443
   ```

2. At the top clearly acknowledge all help you got from Faculty, students, or ANY other source (but for lecture and text). Examples could be "Mary Jones pointed out to me that I needed to draw the second FBD in problem 2." or "Nadia Chow showed me how to do problem 3 from start to finish." or "I basically copied this solution from the posted solutions." etc. If the TA thinks you are taking too much from other sources he/she will tell you. In the mean time don't violate academic integrity rules: be clear about which parts of your presentation you did not do on your own. More on academic integrity see:
   `http://cuinfo.cornell.edu/Academic/AIC.html`

3. All computer output should have your name clearly visible, as printed by the computer (e.g., title plots with your name, put your name in a comment in the first line of any .m files, etc.)

4. Your work should be laid out neatly enough to read by someone who does not know how to do the problem. Part of your job as an engineer is not just to get the right answer, but convincingly so. That is your job on the homework as well.

5. Be concise, don't burden the TA's with page after page of computer output (wallpaper) or lengthy derivations. Blaise Pascal (1623–1662) once wrote to a friend: "This letter is rather long, because I didn't have the time to make it shorter."

When in doubt about these rules and regulations, please contact me.

Grading

Total course grading is 70% homework and 30% final project. Homework is the average of the weekly homework assignments. Final project is the grading of the written report on the final project (strictly individual!).

Web site

`http://bicycle.tudelft.nl/schwab/` or Google arend schwab
Visit my web site for up-to-date info, homework assignments and handouts.

Literature

There are some lecture notes for this course. On the other hand there is a vast amount of literature in the field of Multibody System Dynamics. Most books can be found in the central library.

Multibody System Dynamics

1. D.T.Greenwood, *Advanced Dynamics*, Cambridge University Press, 2003.
2. A.A. Shabana, *Computational Dynamics*, Wiley, New York, 2001.
3. M. Géradin, A. Cardona, *Flexible Multibody Dynamics: A Finite Element Approach*, Wiley, Chichester, 2001.
4. R. von Schwerin, *Multibody System Simulation: Numerical Methods, Algorithms, and Software*, Springer-Verlag, 1999.
5. H. Baruh, *Analytical Dynamics*, McGraw Hill, 1999.
6. A.A. Shabana, *Dynamics of multibody systems*, Wiley, New York, 1998.
7. E. Eich-Soellner, C. Führer, *Numerical Methods in Multibody Dynamics*, B.G.Teubner, Stuttgart, 1998.
8. F.C. Moon, *Applied Dynamics*, Wiley, New York, 1998.
9. M. Géradin, D. Rixen, *Mechanical Vibrations, Theory and Application to Structural Dynamics*, Wiley, New York, 1994
10. J. Garcia de Jalon, E. Bayo, *Kinematic and Dynamic Simulation of Multibody Systems. The Real-Time Challenge*, Springer-Verlag, New-York, 1994.
    Free available at `http://mat21.etsii.upm.es/mbs/bookPDFs/bookGjB.htm`
11. R.L. Huston, *Multibody dynamics*, Butterworth-Heinemann, Stoneham, 1990.
12. W.O. Schiehlen (ed), *Multibody systems handbook*, Springer-Verlag, Berlin,1990.
13. E.J. Haug, *Computer aided kinematics and dynamics of mechanical systems, Volume I: Basic methods*, Allyn and Bacon, Boston, 1989.
14. P.E. Nikravesh, *Computer-aided analysis of mechanical systems*, Prentice-Hall, Englewood Cliffs, 1988.
15. R.E. Roberson, R. Schwertassek, *Dynamics of multibody systems*, Springer-Verlag, Berlin, 1986.
16. J. Wittenburg, *Dynamics of systems of rigid bodies*, Teubner, Stuttgart, 1977.

Dynamics, general

1. T. R. Kane and D. A. Levinson, *Dynamics, theory and applications*, McGraw Hill, 1985.
2. H. Goldstein, *Classical mechanics*, 2nd edition, Addison-Wesley, Reading, 1980.
3. C. Lanczos, *The variational principles of mechanics*, 4th edition, University of Toronto Press, Toronto, 1970.
4. L.A. Pars, *A treatise on analytical dynamics*, Heinemann, London, 1965.
5. G. Hamel, *Theoretische Mechanik*, Springer-Verlag, Berlin, 1949.
6. A. Sommerfeld, *Vorlesungen ueber theoretische Physik, Band I: Mechanik*, Klemm, Wiesbaden, 1949.
7. E.T. Whittaker, *A treatise on the analytical dynamics of particles and rigid bodies*, 4th edition, Cambridge University Press, Cambridge, 1937.

Linear Algebra

1. G. Strang, *Linear algebra and its applications*, 3rd edition, Harcourt Brace Jovanovich, San Diego, 1988.
2. G. Strang, *Introduction to applied mathematics*, Wellesley-Cambridge press, Wellesley, 1986.