MWL The Marcus Wallenberg Laboratory for Sound and Vibration Research

COURSE INFORMATION – NON-LINEAR VIBRATIONS 2020

Code: SD3180

Credits: 7.5

Lecturer and examiner: Leif Kari 070-798 7974 leifkari@kth.se

Prerequisites: Undergraduate courses in mechanics and mathematics including analysis in one and several variables, differential equations and transforms, particle dynamics and mechanical waves or similar.

Motivation: Non-linear phenomena are of fundamental importance in engineering and science – particularly within the field of vibrations and acoustics. These phenomena include shock wave development, self-sustaining oscillations, super- and sub-harmonic responses, to mention a few. Although significant research progress is attained during the last years, covering non-linear ideas, analytical methods, numerical and physical experiments of major mathematical and physical interest, there are still only a few courses devoted to non-linear phenomena and methods – particularly in the vibration and acoustical field. The primary purpose of this course is to fill that void. Interesting examples from the sustainable development context are treated, including ecological, economic and social sustainability.

Outline: This course is learning-centered, supporting a view of learners as active participants in their own learning while using continuous formative assessments with no need for a final examination. To this end, the learners are supposed to take active part in the lectures; encompassing active discussions and experimentations – to mention a few – but also involving active reflective observations while promoting creative solutions.

Contents: Conservative and non-conservative systems, forced oscillations of systems, continuous systems and traveling waves.

Methods: Perturbation methods – such as straightforward expansion, Lindstedt-Poincaré method, method of multiple scales, method of harmonic balance, method of averaging – and basic numerical methods.

Objectives: The general instructional objectives, stated as intended learning outcomes in student performance terms, together with those of specific learning outcomes, incorporate:

1. Applies perturbation methods to new situations:
   i. Predicts the response of a novel, non-linear system – approximated by a conservative, finite degree-of-system – using a perturbation method.
   ii. Predicts the response of a novel, non-linear system – approximated by a non-conservative, finite degree-of-system – using a perturbation method.
   iii. Calculates all the resonance frequencies of a forced, novel, non-linear system – approximated by a non-conservative, single degree-of-system – using a perturbation method.
   iv. Demonstrates a correct use of a perturbation method in the prediction of the standing wave response of a novel, non-linear continuous system – such as string, beam, plate or shell.
   v. Predicts the traveling wave response of a novel, non-linear continuous system using a perturbation method.
   vi. Apply perturbation methods in the sustainable development context including ecological, economic and social sustainability. Examples include predicting shock wave propagation in transportation systems, shock wave propagation and diffusion of dangerous virus over societies.

2. Analyzes non-linear vibration phenomena:
   i. Identifies the non-linear phenomena for finite degree-of-freedom systems.
   ii. Points out the reasons for the non-linear phenomena for finite degree-of-freedom systems.
   iii. Identifies the non-linear phenomena for continuous systems.
   iv. Points out the reasons for the non-linear phenomena for continuous systems.
   v. Points out the reasons for the non-linear phenomena for the sustainable development examples

3. Judges the value of applied perturbation methods at a given application:
   i. Writes a short exposition evaluating the relative merits of the applied perturbation methods.
   ii. Compares the response results predicted by a perturbation method with those of a basic numerical method.
   iii. Explains the reasons for a good match between results obtained by a perturbation method and those of a basic numerical method.
   iv. Explains the reasons for any mismatch between results obtained by a perturbation method and those of a basic numerical method.
   v. Judge and evaluate the perturbations methods applied for the sustainable development examples

4. Contribute to the overall learning outcomes for the student within the environment and sustainable development, including:
   i. Reflect on and discuss the possibilities to use advanced mathematical tools within the scope of sustainable development including ecological, economic and social sustainability
   ii. Describe, evaluate and apply various technology-specific methods and strategies used in the development and design of products, processes and systems that contribute to sustainable development.

iii. To be able be able to discuss and evaluate various technology-specific strategies to strengthen environmental impacts and prevent negative impacts.

5. Displays a scientific attitude towards non-linear problems:
   i. Demonstrates curiosity in identifying non-linear problems.
   ii. Seeks natural causes of non-linear phenomena.
   iii. Demonstrates open-mindedness when seeking solutions.
   iv. Suspends judgments until all evidence is available.
   v. Shows objectivity in analyzing evidence and drawing conclusions.
   vi. Shows willingness to revise conclusions as new evidence becomes available.

Home assignments: (All students)

The learning outcomes are continuously assessed by totally about 4-5 home assignments where methods learned and skills developed during the course are applied to *new* situations while requiring both analyzing and evaluation of the results and methods used. It is permissible to cooperate on the assignments, but they must be handed in individually and written in pencil (no computer print outs).

Scientific paper review:

A recently published scientific paper using some of the method learned is individually reviewed during the final part of the course. The method used and results shown are critically evaluated while also suggesting some alternative approaches. The results of this review are given at a seminar and in a short individual report – covering approximately one to two A4 papers.

Examination: No final examination.

- Approved home assignments handed-in in time (INL1)
- Approved scientific paper review seminar and report (PRO1)

- INL1 - Assignment, 6.0 credits, Grading scale: G
- PRO1 - Project work, 1.5 credits, Grading scale: G

Grading scale: P, F

Based on recommendation from KTH's coordinator for disabilities, the examiner will decide how to adapt an examination for students with documented disability.

The examiner may apply another examination format when re-examining individual students.

Evaluation: Formative and summative course evaluations are to be used.

Literature: "Non-linear Acoustics" Leif Kari – lecture notes

"Nonlinear Oscillations" by AH Nayfeh & DT Mook,
John Wiley & Sons, ISBN: 0471035556, 1979 (Hardcover) or
Wiley Classics Library, ISBN: 0471121428, 1995 (Paperback)

Reference literature:

"Perturbation Methods" by AH Nayfeh,
John Wiley & Sons, ISBN: 0471630594, 1973 (Hardcover) or
Wiley Classics Library, ISBN: 0471399175, 2000 (Paperback)

"The Duffing Equation: Nonlinear Oscillators and their Behaviour" by Ivana Kovacic and Michael J. Brennan (Editors), John Wiley & Sons, ISBN: 978-0-470-71549-0, 2011

"Linear and Nonlinear Waves" by G.B. Whitham,
John Wiley & Sons, ISBN: 0471940909, 1974 (Hardcover) or
Wiley-Interscience, ISBN: 0471359424, 1999 (Paperback)

"Introduction to Perturbation Techniques" by AH Nayfeh,

John Wiley & Sons, ISBN: 0471080330, 1981 (Hardcover) or
Wiley Classics Library, ISBN: 0471310131, 1993 (Paperback)

Course material:

Covered mainly by "Non-linear Acoustics" Leif Kari – lecture notes

Sustainable development (SD):

The teaching, learning and examination activities are strongly interconnected in this course. Lessons introduce the methods and are based on previous student experiences including sustainable development aspect such as mechanical energy transformation into heat and how to model it more accurately and realistic. Examination consists of home assignments applying methods learned to other areas including shock wave propagation in transportation systems and means to avoid it (economical, ecological SD), diffusion of dangerous virus over societies (societal, economical SD) and evaluations of the methods applied. There are also societal aspects discussed during the course. Finally, the students review recently published scientific papers on non-linear acoustic possibly including sustainable development aspect, writing a report and present it on a seminar.

Preliminary program:

Le – Lession, LK – Leif Kari

Nr	**Time**	**Place**		**Program** (*Preliminary*)
Le 1	Mon 24 Aug 10-12	MUNIN/ HUGIN[1]	LK	Information **Chapter 1 –** Introduction
~~Le~~	~~Thu 27 Aug 10-12~~	~~Digitally~~		~~**Cancelled!**~~
Le 2	Mon 31 Aug 10-12	Digitally[2]	LK	**Chapter 2 –** Conservative Systems
Le 3	Thu 3 Sep 10-12	Digitally	LK	Continued
Le 4	Mon 7 Sep 10-12	Digitally	LK	Continued
Le 5	Thu 10 Sep 10-12	Digitally	LK	**Chapter 3** – Non-Conservative Systems
Le 6	Mon 14 Sep 10-12	Digitally	LK	**Chapter 4** – Forced Systems

[1] Room Munin/Hugin, Teknikringen 8, ground floor
[2] Zoom, link will be sent by email

Le 7	Thu 17 Sep 0-12	Digitally	LK	**Chapter 5** – Waves in Continuous Systems
Le 8	Mon 21 Sep 10-12	Digitally	LK	Continued
Le 9	Thu 24 Sep 10-12	Digitally	LK	Continued
Le	Mon 28 Sep 10-12	Digitally	LK	Extra time, in case of (to be decided)
~~Le~~	~~Thu 1 Oct 10-12~~	~~Digitally~~	~~LK~~	~~**Cancelled!**~~
Le 10 (Sem)	To be decided	Physically	LK[3]	Review seminar

Questions: Leif Kari is available for answering questions arising before, during or after the course.

MOST WELCOME!

[3] Physical room, to be decided